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Flood and Coastal Defence R&D Programme

Broad Scale Ecosystem Impact Modelling Tools:
Scoping Study

R&D Technical Report

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This document provides guidance to Defra and Environment Agency staff, research contractors and external agencies involved in the production of R&D outputs for the Joint Defra / Environment Agency Flood and Coastal Defence R&D Programme.

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Introduction

This report details the scoping study for future research and development to support Broad Scale Ecosystem Impact Modelling (BSEIM). The report was commissioned by the Defra & Environment Agency Flood and Coastal Defence R&D programme and undertaken by a consortium led by Cascade Consulting. The objective of the study is "to provide an overview of the topic of BSEIM and define an appropriate and cost-effective research programme".

Policy and Regulatory Drivers

There are a number of policy and regulatory drivers that have stimulated this research, linked to the requirement to better understand the impacts of policies and subsequent measures on the environment and thereby to protect and enhance supported ecosystems. The main drivers include the Strategy for Flood and Coastal Defence in England and Wales (MAFF, 1999) and initiatives to plan flood and coastal management more sustainably, recognised through fluvial Catchment Flood Management Plans (CFMP) and estuarine/coastal Shoreline Management Plans (SMP). A wide range of other planning processes also interact, most notably the Water Framework and Habitats regulations, and the Planning Authorities development planning process.

User Focus

Defra and the Environment Agency recognise the need to consider and cater for the needs of a wide range of users within the flood management process, ranging from governmental policy makers to the public as stakeholders. The study has therefore sought to develop an R&D programme that will allow production and dissemination of information at a number of levels appropriate for the intended end use. A workshop was convened to establish the technical user requirements and a number of case studies were used to identify existing operational methodologies and gaps that may need to be filled.

The outcome of the consultation was a clear call for a more integrated approach to BSEIM. A range of tools are required that can simulate ecosystem impacts at varying spatial and temporal resolutions, for both freshwater and estuarine/coastal systems. Users have also specified the development of a decision support system to help with collation and assessment of ecosystem data, and interpretation of modelling outputs.

Scientific Background

Successful simulation of broad scale ecosystem impacts will require modelling tools that can predict the changes in hydraulic, hydrodynamic, geomorphological and ecological systems and the interactions and feedback loops between each. However, it is acknowledged that at present the tools to undertake such simulations are far from perfect. The simulation of geomorphological change and dynamic ecological consequence require significant levels of investigation and testing, for both freshwater and estuarine/coastal systems.

Modelling of geomorphological function has started to develop in the past few years and there are now a number of riverine and estuarine/coastal models that can predict with some confidence the longer term changes in channel, estuary and coastal morphology. Simulation of geomorphological change specifically to input into ecosystem assessment is less well understood. Linking changes in geomorphology to ecosystem effects is still in its infancy and requires a long term research commitment.

A number of modelling approaches have been developed to simulate specific ecosystem impacts from a variety of activities, including proprietary models such as MIKE11, ISIS and PHABSIM, and a number of empirical models of predator/prey interactions. It is generally acknowledged that none of the models so far developed can adequately simulate ecosystem impacts at the broad scale required for policy appraisal. The report identifies a wide range of potential modelling approaches that could be adapted to improve ecosystem impact assessment, many of which could usefully be incorporated into raster based GIS compatible frameworks – these include for example cellular automata, individual based models and metapopulation models. Key to future modelling tool development will be the ability to adapt to a range of scales and input variables, which can be accommodated within a GIS platform. An example is given in the main text of a rudimentary ecosystem impact modelling approach that could form the basis of the long term research effort, based on a catchment based GIS platform, incorporating land use as a major influencing factor, hydraulic and geomorphological interactions, and (at present) simple simulation of the main ecosystem components. Over time each element could be integrated and through iteration of the framework, using specific case study catchment/coastal areas, be developed to provide a modelling system that can simulate relative changes in ecosystem function resulting from changes in specific activities and measures.

The modelling tools developed will be subject to errors associated with sampling, assumptions used, error amplification within and between models, errors in the assumed basis for links between models, stochastic errors and so on. There is a risk that the outputs from some of the R&D will not be very effective in supporting decision-making. It is important to note this possibility at the outset and put in place measures to minimise the amplification of errors through the modelling process. It is recommended that such risks are controlled by establishing a steering group that has suitable expertise and accepted responsibility to assess the risks associated with individual projects. The risk assessment and analysis of each project should be a standing item on the proposed project steering group bi-annual meetings.

Data are recognised as having a major constraining influence on future modelling success. Without a fundamental understanding of the baseline ecosystems being simulated, and equally the potential dynamic changes in that ecosystem in response to new influences (either natural or man induced), it will not be possible to predict with any certainty the outcome of specific policies or measures. A more co-ordinated ecosystem monitoring and data collation system is required for flood management purposes, together with a better understanding of ecosystem interactions. Equally the response of ecosystems to specific flood management measures and influences will need to be better understood.

Successful ecological impact models will continue to make uncertain predictions. To assure the delivery of benefits, users will still need to undertake adaptive management that defines the correct complexity of modelling tools for a given task and allows continued improvement of the models that reduces future uncertainties. Given the current reluctance to undertake post-project appraisal, the future opportunity to promote adaptive management and on-going improvement should not be lost, and is highly recommended by this research.

Future R&D Programme

The future modelling strategy should be based on four key elements: the strategy will have to be flexible (in both scale and sub-model interaction), be user friendly, operate at the lowest level of possible complexity and be capable of visualisation. To achieve this end point, a number of R&D outputs are required that improve our understanding of the following:

Ecosystem Model Input Data

- Hydrological, hydrodynamic and geomorphological modelling and data inputs
- Catchment/coastal cell ecosystem baseline descriptions
- Processes contributing to the dynamic evolution of floodplain and estuarine/coastal ecosystems

Ecosystem Modelling Tools

- Quantitative modelling approach for river catchments
- Quantitative modelling approach for estuarine and coastal cells
- Decision support tools to aid users adopt models and interpret outputs

The BSEIM R&D programme will be divided into short, medium and long term elements. Seven projects are recommended, the first of which (BSEIM toolbox) should focus on compilation of existing information and methodologies suitable for immediate application in support of CFMP and SMP ecosystem assessments.

Project	**Description**
Short term – within 2 years	
BSEIM 1	BSEIM toolbox – phase 1.
BSEIM 2	Hydrological, hydrodynamic and geomorphological model development.
BSEIM 3	Development of ecosystem impact modelling approach – Phase 1.
Medium term – 2 to 5 years	
BSEIM 4	Updating BSEIM toolbox – phase 2.
BSEIM 5	Ecosystem impact model development – field trials and model integration.
Long term - 5 to 10 years	
BSEIM 6	Mid-term review of progress.
BSEIM 7	Further ecosystem impact model development.

Budgets have been identified for each of the BSEIM studies. The budgets are acknowledged to be relatively modest for such a fundamentally challenging R&D programme. However, the view has been taken that since only a limited budget will be made available, the modelling programme will be focused to achieve the greatest benefit by pragmatic delineation between research aspiration and operational necessity. The modelling tools will be necessarily "fit for purpose" rather than "all singing and dancing".

The short term programme has a recommended budget of £490,000 and should produce BSEIM guidance and a first phase of ecosystem impact modelling tools. The medium term programme has a budget of £565,000 and will build on the initial modelling programme to arrive at a GIS based modelling framework that is capable of simulating the relative impacts of flood management measures. The long term programme should be re-assessed after the first two year programme and re-focused as necessary. It is likely that many gaps will remain after the medium term programme in our understanding of the interactions between hydrology, geomorphology and ecology. Continuation of, and further specification of, field-based research is likely and a budget should be allocated to allow these research benefits to be realised, increasing our confidence in the BSEIM models. A budget of £1,150,000 is recommended for the 5 to 10 year programme.

Given the very considerable task of developing BSEIM modelling tools that can simulate ecosystem change with confidence, the budgets identified are likely to require supplementing from other sources. A number of co-funding opportunities are identified, most notably through the Estuary Research Programme and other complimentary R&D programmes, including for example the Water Framework and Habitats Directives research initiatives.

1 INTRODUCTION

1.1 Overview

This scoping study was commissioned by the Department for the Environment, Food and Rural Affairs (Defra) and the Environment Agency to establish the existing and future requirements for Broad Scale Ecosystem Impact Modelling (BSEIM) tools to support analysis of potential future flood management policy initiatives. The report summarises the scoping study carried out by a consortium led by Cascade Consulting in association with HR Wallingford, the Institute of Estuarine and Coastal Studies at the University of Hull, Land Use Consultants and CoMPLEX at University College London.

The study is a component part of a wider flood and coastal defence research initiative resulting from the review of government-funded R&D reported by Professor Penning-Rowsell (MAFF, 1999). Six themes have been identified and adopted to form a joint Defra/Environment Agency R&D programme, as shown in Figure 1.1.

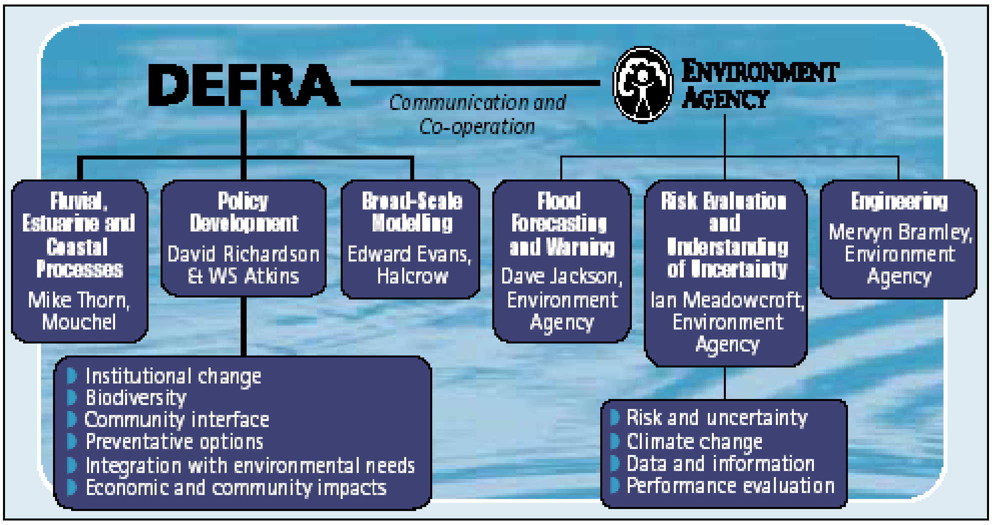


Figure 1.1 Thematic Structure of the Defra & Environment Agency Flood and Coastal Defence R&D Programme

Within this framework the Broad-scale Modelling (BSM) theme is concerned with predicting large-scale, medium to long-term natural evolution and the influence that climate change and anthropogenic intervention may have. This will aid with the determination of regional and national economic impacts through to the optimum allocation of resources. Outcomes from the Theme will deliver tools to better assess the individual and cumulative impacts of alternative planning scenarios, flood plain policies and future catchment and coastal zone management practices that may result from future flood management initiatives. BSEIM is an integral part of the BSM process, which will require the evaluation of the environmental and ecological implications of the variety of future flood management policies and practices.

However, the six Themes are necessarily interlinked. BSEIM has strong ties with the Fluvial, Estuarine and Coastal Processes Theme, which seeks to describe and quantify all of the important processes that contribute to the evolution of river, estuarine and coastal systems. Similarly, the Engineering Theme has elements of river and catchment-related performance that incorporate for example projects to understand the flow over flood plains (includes the influence of vegetation) and the use of soft engineering solutions. Lastly, the Policy Theme has an overarching purpose to facilitate the adoption and implementation of policy measures which improve understanding, reduce risk and costs, and most importantly, improve decision making and result in better value for money. Each of the Themes therefore has a clear interaction with the inputs to and outputs from the BSEIM scoping study which have been considered throughout.

The Thematic structure seeks to cover all of the aquatic media that are of concern for flood management, ranging from fluvial systems to estuaries and coastal waters.

1.2 Objectives

The overall objective of the scoping study is taken from the project Terms of Reference (given in full as Appendix 1):

- To provide an overview of the topic of BSEIM and define an appropriate and cost-effective research programme.

Specific aims of the scoping study are to:

- Establish the environmental policy drivers and how these influence flood risk management
- Establish the user requirements, within the context of flood risk management, for BSEIM utilising case studies and other methods.
- Establish the existing Scientific Engineering and Technology (SET) base with respect to BSEIM.
- Establish the current approaches used to estimate the impact of climate and anthropogenic change on ecosystems at a broad scale;
- Establish the links between BSEIM and other ongoing/future initiatives and research;
- Establish short-term, medium-term and long-term future research and development requirements; and
- Ensure that future BSEIM R&D is user-focused, is based upon consultation and consensus within the research/user community, and has agreement from the sponsors.

In addition to the original project specification, as the project progressed it was recognised that the assumptions made regarding the availability of hydrological and geomorphological input data, on which ecosystem modelling tools would be based, are not likely to be available in the required format within the foreseeable future. An addendum to the project specification was therefore agreed to develop an R&D agenda for geomorphological tools to supply and supplement the data required for BSEIM. The additional inputs were provided by Professor Keith Richards (Cambridge University) and Dr Stephen Hull (ABP).

2 POLICY DRIVERS AND REGULATORY REQUIREMENTS

A number of international and national policy initiatives have either direct implications for flood management or have an indirect effect that may influence flood management practices. Overall management actions in the freshwater and marine environments may be regarded as having to fulfil six ideals: they should be environmentally sustainable, technologically feasible, economically viable, legally permissible, socially desirable and administratively achievable. Hence any response to flood and coastal management should be related to these ideals. It is important to recognise the complex matrix of policy drivers that may contribute to flood management practices, as these are likely to define the regulatory framework for ecosystem impact assessment and hence the requirement for BSEIM. The following Section analyses the range of drivers and their potential implications.

2.1 Principal Flood Management Policy Drivers

There are a number of policy drivers that are of significance to flood management ranging from the strategy for flood and coastal defence for England and Wales, with its supporting guidance, to the regional/catchment plans required by the strategy. These include Shoreline Management Plans (SMPs), Catchment Flood Management Plans (CFMPs) and Water Level Management Plans (WLMPs). The policies and guidelines that may influence the requirement for BSEIM are reviewed below.

2.1.1 Strategy for Flood and Coastal Defence in England and Wales (MAFF, 1993)

The strategy sets out the Government's (formerly MAFF and now Defra) policy aims and objectives for flood and coastal defence. It aims to reduce the risks to people and the developed and natural environment from flooding and erosion by encouraging the provision of technically, environmentally and economically sound and sustainable defence measures. Key objectives are:

1. Provision of adequate and cost-effective flood warning systems.
2. Provision of adequate, technically, environmentally and economically sound and sustainable flood and coastal defence measures.
3. To discourage inappropriate development in areas at risk from flooding or coastal erosion.

The importance of this strategy is that it sets a broad policy context for flood management, to be supported by broad-scale coastal and fluvial flood management planning established through SMPs, CFMPs and WLMPs. The strategy states that flood management schemes should only be developed that are judged to be environmentally acceptable, with the potential impact on habitats and the environment generally to be a key consideration. Natural river and coastal processes should not be disrupted except where human life or important man-made or natural assets are at risk. This policy should continue and be elaborated upon in the subsequent planning stages. Recognition of the importance of the integrity of habitats and nature conservation more generally at this strategic level should dictate that subsequent plans incorporate a suitable level of impact assessment. This is likely to require a suitable range of BSEIM tools.

2.1.2 High Level Targets For Flood and Coastal Defence Operating Authorities (MAFF, 1999)

"High Level Targets" are templates to guide flood and coastal defence management authorities in preparing their plans. Development of the Targets in 1999 was found to be necessary to ensure a more certain delivery of the Government's policy aims and objectives. Each operating authority (the Agency, Internal Drainage Board and/or local authority) should produce policy statements which establish the link between the Government's aims and objectives for flood and coastal defence and demonstrate how these are being implemented in the local area. These should "comply with sustainability policies….statutory environmental obligations and contribute to relevant biodiversity targets".

High Level Target 9 is of key importance, stating that when carrying out flood and coastal defence works, operating authorities shall aim to:

1 Avoid damage to environmental interest
2 Ensure no net loss to habitats and species covered by Biodiversity Action Plans (BAPs)
3 Seek opportunities for environmental enhancement

These responsibilities will clearly need to be discharged through careful consideration of flood management policies and prediction of ecosystem effects from derived practices. BSEIM is likely to be required to support such decisions.

Target 8 relates to completion or updating of SMPs, with the environmental considerations that these entail (see below). Target 10 requires detailed programmes for implementation and review of WLMPs for European conservation sites (by April 2002) and SSSIs (by April 2003). Target 11 requires identification of sites where CHaMPs are needed, that will avoid damage or deterioration of Natura 2000/Ramsar sites. Each of these Targets will require consideration of flood management policies and practices, and the consequent effect on relevant ecosystems. Since the Targets are necessarily strategic, BSEIM tools are likely to be required. Further details of the various plans are given later in this Section.

2.1.3 Flood and Coastal Defence Project Appraisal Guidance (FCDPAG)

There are six guidance documents (FCDPAG 1-6) that provide best practice advice to practitioners involved in the preparation of flood defence strategies and schemes. Ecosystem and ecological considerations are integral to the development of the strategic plans. For example, in FCPAG2 (Strategic Planning and Appraisal Guidance) the strategic approach for coastal and estuarine flooding should "desire" to maintain or enhance the environmental value of the beach and shoreline or "identify" opportunities for long term retention and enhancement of environmental features, respectively. Significantly, there is also guidance on flood alleviation taking into account internationally designated environmental sites, which relates the strategic approach to the CHaMP process (see below).

The key document that incorporates a requirement for consideration of ecosystem implications is FCDPAG 5 (environmental appraisal). It provides guidance for operating authorities to ensure proper account is taken of environmental considerations when preparing schemes for flood and coastal defence works. The document places specific emphasis on nature conservation, particularly sites of international importance, and requires detailed consideration of options that deliver environmental benefits or minimise damage. The document facilitates integration with other policy drivers, such as Water Level Management Plans, Estuary Management Plans, Shoreline Management Plans, and any other relevant strategic documents.

2.1.4 Shoreline Management Plans

SMPs aim to set out a strategy for sustainable coastal defence within sediment cells over the next 50 years, taking account of natural coastal processes and human and other environmental influences and needs. Guidance on SMP production was originally issued in 1995 and has recently been updated to incorporate better integration with the planning system and consideration of environmental impacts (Defra, 2001). To this end, the new guidance has an objective to "comply with international and national nature conservation legislation and biodiversity obligations".

SMPs can develop five generic coastal defence policy options that may in the future require assessment with BSEIM tools:

1. Do nothing
2. Hold the existing defence line through maintenance or changing the standard of protection
3. Advance the existing defence line
4. Retreat the existing defence line (through managed retreat or realignment)
5. No active interventions.

Notably, when deciding upon appropriate flood management policies and options, including those identified above, the revised guidance highlights assessment and development of options that prevent loss or degradation of nature conservation sites. The guidance also specifies the use of land use planning guidance, including Planning Policy Guidance note PPG 9 (Nature Conservation) that strongly emphasises ecosystem impact assessment. SMPs should therefore incorporate an assessment of the implications of defined policies and options on sensitive ecosystems, which may require strategic assessment and prediction using BSEIM tools.

In terms of this report, the ecosystem assessment requirements of SMP are considered within the remit of the CHaMP process (see Section 2.1.7). Where SMPs do not have international designations within the boundaries, and therefore no CHaMP, there will also need to be consideration of ecosystem issues. The general principles relating to habitat, community and species interactions and the need for appropriate ecosystem modelling tools will apply equally to the non-designated sites.

2.1.5 Catchment Flood Management Plans

CFMPs are high-level flood management planning documents for riverine systems that will form an important element of the strategy for flood and coastal defence in England and Wales. Five pilot CFMPs are currently being developed for the Rivers Medway, Derwent, Severn, Irwell and Parrott. Recent draft guidance (Environment Agency and MAFF, 2001) states that CFMPs must be based on a sound understanding of the hydrological, hydraulic and hydrogeological, and geomorphological processes at work in the catchment, along with flood defence needs, environmental considerations, planning issues, current and future land use.

There is a growing emphasis in the regulatory guidance on the assessment of environmental impacts, leading to a situation where "implementation of policies should have no significant detrimental effect on the environment, and where possible, opportunities will be sought for environmental enhancement". However, …"This will not always be possible, but should be a key goal at CFMP level". In essence this strategy requires managers to determine what is the natural situation, how it has changed and whether the management measures implemented will have the appropriate and desired effect. As such there is the need either for physical comparison of areas to indicate change, hindcasting and predictive modelling at one or more spatial and temporal scales. Within the guidance there is clear direction on the requirement for broad-scale modelling, and specifically prediction of ecosystem effects. This will require identification and development of a suite of suitable BSEIM tools.

2.1.6 Water Level Management Plans

WLMPs provide a means by which the water level requirements for a range of activities in a particular area, including agriculture, flood defence and conservation can be balanced and integrated. Priority has been given to preparing plans on sites of international importance (SACs, SPAs, Ramsar sites) and national importance (SSSIs). Recent Defra consultation indicates that implementation of WLMPs is to be encouraged, including those situations where the benefit is solely for conservation. The interactions of water level and supported ecosystems is likely to require further investigation as part of the BSEIM suite.

2.1.7 Coastal Habitat Management Plans

CHaMPs aim to balance coastal defence needs and the conservation objectives required under the Habitats and Bird Directives by avoiding damage or deterioration of Natura 2000/Ramsar sites. The plans are intended to assist in the development of sustainable coastal defence strategies in areas where coastal defence measures have implications for internationally important wildlife sites, including:

1. Special areas of conservation (SACs) under the EU Habitats Directive
2. Special protection areas (SPAs) under the EU Birds Directive
3. Wetlands protected under the Ramsar Convention.

At present there are 7 pilot CHaMPs, at Winterton Dunes, North Norfolk, Suffolk coast and estuaries, Essex coast and estuaries, North Kent coast, Dungeness and Petts Levels, and the west Sussex and Hampshire coast. The draft plans have not yet been developed and further work is required to refine the guidance. It is anticipated that relevant information in the CHaMPs will be incorporated in future revisions of the SMPs. The next revision of the SMPs is due to start in 2003. The purpose of the ChaMPs is to act as an accounting system to record and predict losses and gains in habitats and species of European interest due to shoreline change and to set the strategic direction for conservation measures over an extended 30 to 100 year timeframe. In order to support these aims, it is likely that predictive BSEIM capabilities will be required.

2.1.8 EC Water Framework Directive - River Basin Management Plans

The EC Water Framework Directive provides a statutory requirement both for flood defence and the maintenance and (where required) improvement of ecological status of surface waters. A principal aim (Article 1(e)) of the Water Framework Directive is to contribute to mitigating the effects of floods. In parallel, the Directive requires that all surface (including transitional, rivers and coastal) waters must achieve good ecological status at the latest 15 years after the date of entry of the Directive. Article 13 of the Directive requires member states to produce river basin management plans, which must set out the programme(s) of measures to achieve the aims of the Directive. Programmes of measures for flood and coastal defence may include restoration of habitats as an integral part of flood defence works to aid in achieving good ecological status. The Directive is likely to place an onus on operating authorities to consider environmental improvements that will be required to comply with the Directive, i.e. good ecological status. These measures are likely to require predictions of the implications of flood management and development activities on ecosystem integrity that will require a BSEIM capability.

2.2 Policy Drivers and Regulatory Requirements that Influence Flood Management Planning and Ecosystem Assessment

In addition to the direct flood management policy drivers, there are a number of over-arching and/or indirect considerations that will place an emphasis on ecosystem assessment as part of future flood management policy appraisal. These range from requirements within legislation such as the Environment Act 1995 and Countryside and Rights of Way (CROW) Act 2000 to specific actions from nature conservation interests. The following Section briefly describes the main drivers and their implications.

2.2.1 Nature Conservation and Protection

Much of the recently developed environmental legislation, including the Environment Act 1995 and the CROW Act 2000 require flood and coastal defence operating authorities to contribute to the conservation of nature, and to further the conservation of, inter alia, flora and fauna, so far as is consistent with their functions. In addition, for international (SAC, SPA and Ramsar) and nationally designated sites (SSSI, NNR etc.) there are specific requirements to maintain and enhance the nature conservation interest. Within the Conservation (Natural Habitats etc.) Regulations 1994, adopted for the implementation of the EC Habitats Directive, there is a requirement to carry out an Appropriate Assessment for plans and projects likely to affect the conservation integrity of a site. Given that such assessment requires the determination of actual or potential change, there is increasingly the need for a predictive capability when carrying out Appropriate Assessments.

The Environment Agency has also developed a number of catchment-based planning initiatives covering their statutory functions. These are likely to take on a more focused role than the Local Environment Agency Plans (LEAPs) that they may replace. These include, for example, Catchment Abstraction Management Plans (CAMS), Salmon Action Plans (SAPs) and Fisheries Action Plans (FAPs). These planning tools will have to be integrated with the flood management plans, and all have a strong ecosystem component. Similarly, the requirement for River Basin Management Plans (RBMPs) under the Water Framework Directive is likely to require a statutory and more integrated approach to catchment planning that will place greater emphasis on long-term predictions of ecosystem function and response to anthropogenic impacts.

Biodiversity (BAP) and habitat action plans (HAP) will also influence future flood management planning. These plans propose actions and targets to maintain or increase biodiversity, in order to implement the UK Biodiversity Action Plan. Many habitats and species action plans affect river and coastal flood plains. Flood and coastal defence schemes also provide an opportunity for operating authorities to contribute to the biodiversity targets set out in Biodiversity Action Plans. The newer flood management planning guidance documents all require BAPs and HAPs to be taken into account and now go beyond this to aim to enhance such sensitive habitats and species where appropriate. BSEIM tools may be required to predict the positive and negative effects on the range of habitats, communities and species of concern.

However, there would appear to be a general lack of ecological strategies and targets for rivers, estuaries and coastal areas for the majority of habitats, communities and species represented. It may result in situations where there is no clear context for decision-making. With a few notable exceptions (eg. SACs), the research community and policy makers do not know what the objectives are for individual catchments or coastal zones from an ecological viewpoint. So, if a decision support model predicts with a high degree of confidence that a salt marsh will change to a mud flat (or vice versa) it may often be difficult to assess whether this matters, unless a suitable strategy has been developed. Although not specifically a task for this research, the project team strongly recommends that without the parallel development and/or wider application of, for example, catchment conservation strategies full use will not be made of the proposed BSEIM tools.

2.2.2 National, Regional and Local Development Planning

Much of the recent development planning guidance (eg. Regional Development Plans, Structure Plans, Local Plans, Unitary Development Plans) contains requirements to consider the environment and specifically nature conservation. This may in many cases relate directly to flood management planning and place greater emphasis on ecosystem impact assessment. Of particular significance may be the recently ratified EC Strategic Environment Assessment (SEA) Directive, together with the existing Environmental Impact Assessment (EIA) Directive. Government guidance on the latter (DETR circular 02/99) clearly states the need to predict the implications of flood relief works over a given threshold on the receiving environment.

In addition to these, the Government has issued a number of PPG notes that have relevance, including PPG20 – coastal planning; PPG25 - Development and flood risk; and, PPG9 - Nature Conservation:

PPG9 - Gives guidance on how the government's policies for the conservation of the natural heritage are to be reflected in land-use planning. The PPG note outlines the approach to be taken to nature conservation in and outside designated sites. The PPG refers to statutory designations (SSSIs, SPAs and SACs), the Wildlife and Countryside Act 1981 and the National Parks and Access to the Countryside act 1949. Non-statutory designations are also referred to: Non-Statutory Nature Reserves and Sites of Importance for Nature Conservation (SINCs).

PPG20 - Covers planning policy for the coastal areas of England and Wales. The PPG states that it is the role of the planning system to reconcile development requirements with the need to protect, conserve and, where appropriate, improve the landscape, environmental quality and wildlife habitats. The PPG covers different types of coastal designation, types of coast (i.e. undeveloped, developed, despoiled, etc), policies for developments and risks, and the coastal zone and development plans.

PPG25 - Takes account of the developing knowledge of the likely impact of climate change. Planning decisions should apply the precautionary principle to avoid inappropriate development in flood risk areas. The Draft Guidance includes an explicit risk-based sequential test that directs authorities and developers towards sites at lower risk from those at higher risk. The PPG also places a strong emphasis on planning in relation to river catchments at all stages in the plan-making process.

2.2.3 Other Initiatives

Environment Agency Physical Quality Objectives (PQOs)

The Agency is required to develop a method to set Habitat Quality Objectives by the end of March 2004. To achieve this their objectives include the development of a methodology for assessing physical quality and tools for identifying issues/pressures at a catchment scale. Any PQOs developed in river catchments will have a direct influence on subsequent flood management planning, as policies and options are likely to need to comply with the stated objectives. The geomorphological driver for this work is also likely to be similar to the approach taken for BSEIM method development, seeking to establish tools to predict short, medium and long term changes to catchment channel characteristics. The work undertaken may be usefully integrated with the BSEIM approach.

Estuary Management Plans (EMPs)

EMPs bring together key stakeholders in a given estuary to address issues of concern with the aim of developing sustainable use of the estuary. EMPs usually address the issues of flood defence and nature conservation, although there is no set framework. Where EMPs have been developed, for example on the River Ribble, Humber estuary and Morecambe Bay, the information they contain can be usefully employed. In many cases, these will be duplicated by the Management Plans developed by the Relevant Authorities groups and schemes of management set up under the EC Habitats Directive. These and the accompanying Advisory Groups for SACs will both provide information for the BSEIM and will be recipients of outputs and predictions.

Coastal Strategies (e.g. Dorset Coast Strategy)

Coastal strategies are voluntary mechanisms that seek to develop the sustainable management of all aspects of the human use of the coast, including coastal defence and nature conservation. As with EMPs, the strategies tend to be diverse and vary in quality. However, the information generated can be of use for BSEIM studies and the policies developed, although voluntary, can carry weight with planning authorities. Development of the strategies could be usefully bolstered by application of BSEIM techniques.

Integrated Coastal Zone Management (ICZM)

ICZM has been developing as a process for many years, but has received renewed impetus recently with a Communication from the EC for implementation of ICZM in Europe (Brussels, 25.9.2001, 2000/0027(COD)). The proposal, if ratified, will require Member States to develop a national strategy to promote ICZM. A key driver is the desire to maintain and enhance the biodiversity of the coastal zone in the face of continued degradation, global warming and sea level rise. If this initiative goes forward, as it is expected to do, then BSEIM tools are likely to be required to predict the implications of flood management policies (amongst many others). For example, the East Riding Integrated Coastal Zone Management Plan (East Riding of Yorkshire Council, 2002) has been developed for one of the UK's fastest eroding coastlines and contains strategies which require an adequate predictive capability.

2.3 Consequences of Drivers for Ecosystem Impact Assessment

In recent years there has been a significant development in the number of flood management policy drivers that actively seek to maintain and where possible enhance the environment. This is combined with a range of other legislative and non-regulatory requirements that require consideration of nature conservation in flood management planning or other associated development. These requirements have been met to date through the application of existing and developing quantitative and qualitative ecosystem assessment approaches. However, it is now recognised that given the range of drivers and the development of statutory requirements for protection of certain nature conservation interests, and the paucity of existing techniques and tools, there is a need to identify and where appropriate develop suitable predictive BSEIM tools.

It is likely that, given the range of policy initiatives, there will be a need for a range of BSEIM tools that can be used at different spatial and temporal resolutions. In addition, the range of policy initiatives and regulatory requirements may require a more holistic suite of the BSEIM tools to incorporate all of the necessary elements at the required resolution. For example, at present there would appear to be a conflict within and between policy areas about the scale of necessary ecosystem assessment. Flood and coastal defence strategy analysis is necessarily at a high level, using low resolution data and hydrological simulation.

However, a requirement to incorporate the effects of plans and projects on SAC sites under the Habitats Directive (which have very specific data and predictive modelling requirements) would tend to suggest that greater resolution is needed in the ecosystem assessment. In addition, the Water Framework Directive has a future requirement for "good ecological quality" in the majority of waters, regardless of nature conservation designations; however, protected sites are given additional protection under the Directive. Discussions are on-going, but many significant flood defence works may fall within the heavily modified water bodies designation, requiring instead "good ecological potential" and having a potential "disproportionate cost" waiver. Notwithstanding, future studies are therefore likely to place greater emphasis on general ecosystem integrity rather than focus on nature conservation sites as is presently suggested for CFMPs and SMPs.

The main repercussion of these policy drivers is that in future it will be necessary to consider ecosystems in a wider context, not just areas with nature conservation designations, and at a greater spatial resolution. Therefore it may be more appropriate, or even necessary, to simulate catchment and coastal zone hydrology, hydrodynamics and geomorphology at greater resolution earlier in the policy assessment process, in order to suitably test the policies against the ecosystem criteria. This issue will be considered in the context of adaptive management strategies later in the report.

3 USER GROUP REQUIREMENTS

3.1 Rationale

The Penning-Rowsell report on government-funded research and development in flood and coastal protection recognised that a key element of future R&D output must be a focus on user requirements and consequent development of tools that users can adopt and use (MAFF, 1999). The six R&D themes have therefore sought to understand user needs and develop R&D programmes that can deliver decision-support tools appropriate to each level of project appraisal.

The BSEIM scoping study has embraced this fundamental approach throughout by:

- Harnessing the experiences of project teams undertaking CFMP and CHaMP studies using Case Study examples and interviews.
- Co-ordination of an expert workshop on BSEIM to better understand user requirements and discussion of possible avenues for future R&D.
- Wide circulation of the draft final report for comment.

The following section details the user group interactions and the outcome of the user group consultations. Four Working Papers were produced in support of the workshop; these are discussed in Section 3.3.

Of principal interest for the scoping study are the problems with the present assessment systems/requirements and the consequent user group decision-support tools needed to deliver the required level of analysis and policy advice. These are summarised in Section 3.4.

3.2 Case Studies

Analysis of a number of case studies was suggested as a good way to identify the main BSEIM issues facing project managers when trying to implement CFMP and CHaMP environmental assessments. An initial list of case studies was agreed by the Steering Group that represented a reasonable spread of geographical and ecological issues:

- River Severn CFMP
- River Medway CFMP
- Humber estuary (developing CHaMP)
- Essex coast and estuaries CHaMP
- Dungeness coast and Petts Level CHaMP

After inspection of the data made available it became clear that there were methodological differences and a lack of guidance on ecosystem issues between and within the CFMP and CHaMP planning approaches, a view confirmed by the respective project managers. No consolidated ecosystem assessments were presented for the Severn and Essex Coast studies within the study timetable. Therefore, rather than detail each case study individually, the general findings of the analysis were therefore consolidated and are summarised below.

3.2.1 Areas of Investigation

For each case study the following areas of investigation were assessed:

- Previous/historic and existing/proposed flood management practice
- Ecosystem sensitivities
- Extent of ecosystem assessment at policy and scheme-specific levels
- Methods of assessment used
- Effectiveness of assessment methodologies employed
- The nature, extent and outcome of any monitoring and post-scheme audit undertaken
- Gaps in assessment from both experts and practitioner's viewpoints
- Recommendations for improvements and predictive methodologies over short, medium and long-term timeframes.

3.2.2 Methods of Assessment Used

A number of methodologies have been adopted, although no consistent approach has been developed to date:

- Qualitative assessment of ecosystem impact based on a variety of approaches and application of professional knowledge and judgement
- Development and application of numerous modelling tools primarily to investigate "bottom-up" causes of impacts on biota, e.g. water flow and sediment transport processes.
- Some initial attempts to integrate/link physical causes and ecological effects, but not very well developed or proven.

3.2.3 Effectiveness of Assessment Methodologies Employed

The effectiveness of the assessment methodologies employed was difficult to determine in all three case studies as the methodologies were employed almost entirely in the pre-scheme phase to justify proceeding with the works. Where schemes have gone ahead either as planned or subject to modification on the basis of assessment recommendations, post-scheme monitoring/audit has been lacking, limited or undertaken for insufficient time to confirm or refute the prediction made. However, this is a constant criticism of EIA in that follow-up, auditing and impact confirmation is rarely carried out in a structured manner. No real feedback into the usability and robustness of the methods could be derived, although the lack of input data of the required resolution (ecological, hydrodynamic and geomorphological) and subsequent predictive ecological methodologies were frequently cited as limiting the effectiveness of the ecological assessment.

3.2.4 Gaps in Assessment Methodologies Employed

A number of gaps were identified, which can be summarised as:

- Insufficient base data from poor or incomplete case-studies
- Highly variable approaches making comparison difficult/impossible
- Lack of generic guidelines on best practice procedures

- No comprehensive studies involving the application of ecosystem tools to integrate, describe, predict and interpret physical causes and ecological effects.

3.2.5 Recommendations for Improvements in Predictive Methodologies Over Short, Medium and Long-term Timeframes

A number of recommendations have been identified through the case study assessment and through detailed discussions with project managers that should be incorporated into the future R&D programme:

- Identification and ranking of those areas and assets at risk, ideally in a GIS format
- Identification and ranking of those areas where new habitat could be created
- Quantification of cost-benefit issues, especially environmental values
- Understanding of the positive and negative impacts of soft engineering techniques
- Representations and simulation of physical processes on a riverine, estuarine and regional scale
- Representations and simulation of physical processes on a scheme specific/local scale
- Integration of regional physical process predictive tools with local ones
- Quantification of the inherent difficulties in ecosystem prediction based on hind-casting and expert judgement
- Development of ecological function predictive tools
- Linkage of physical process predictive tools with ecological function predictive tools.

These recommendations have been taken forward where appropriate within the proposed R&D programme described in Section 5. It should be noted that a significant number of the recommendations relate to the other R&D Themes, particularly the Engineering and Policy areas.

3.3 Workshop and Consultation

3.3.1 Introduction

The purpose of the workshop was to achieve a balanced view of the needs of the whole user community, ranging from policy makers to project managers, practitioners and operational personnel. A wide range of attendees were therefore invited to the workshop, which took place on 16th April 2002 at Defra Nobel House. The list of attendees is given in Appendix 2, and represents a good cross-section of the target users groups, although fewer policy-orientated staff were able to attend than anticipated.

The workshop format was developed to maximise the interaction of the participants, to draw out the major themes requiring attention for the future R&D programme. The workshop structure is detailed in Appendix 2.

The summary outputs from the workshop are discussed in Sections 3.3.2 and 3.3.3 below and reproduced in full as Appendix 3.

Following the workshop the report has been subject to further peer review through a general round of e-consultation during August/September 2002. Comments from the e-consultation have been considered and inserted as deemed appropriate in the final text.

3.3.2 User Group Requirements

A consistent set of issues emerged from the morning session on user group requirements from both the riverine and estuarine/coastal groups. To date research efforts have concentrated on the scientific underpinning of modelling systems with relatively little thought to end user requirements, with the result that R&D has often been poorly exploited by the wider stakeholder community. There has therefore been a problem with engaging the public and influencing political debate. While ecosystem assessment needs to be incorporated earlier in the decision-making process, there are few if any modelling tools to support the rigorous analysis of catchment-based impact assessment. The majority of assessments to date have not been coordinated, and have focused on local reach-specific assessments rather than broad-scale effects.

Adaptive Management

There was a general call for a suite of BSEIM tools that are amenable to adaptive management, where the level of complexity is linked to the scale of the problem and the level of data/modelling sophistication required. A general problem was highlighted with the confidence of model outputs, particularly for more complex simulations over long time series. Recognition will have to be taken of the potential to compound inaccuracies from the hydrodynamic and geomorphological predictions, which may be magnified through extrapolation of biological interactions, particularly when predicting changes over decades.

Decision Support Tools

There was some discussion regarding the available level of expertise amongst the user-community: even if the relevant and appropriate tools were developed, would they be able to implement and use them? It will also be necessary to produce a BSEIM toolbox that can be exploited by individuals with a range of technical expertise. There is a requirement for a simple user-interface for operational and stakeholder groups to access the more basic levels of data and information. The more sophisticated modelling tools will need to be utilised by technical experts. Provision of suitable training at a variety of levels appropriate to each user group (e.g. basic ecosystem knowledge through to modelling applications) was emphasised by most participants, together with a call to establish the BSEIM toolbox as an aid to decision-making (i.e. as a decision support system) rather than the decision-maker – previous experience has shown that the latter approach can alienate the proposed user groups.

3.3.3 Scientific Base

In considering the scientific base for BSEIM tools there were many similarities between the catchment-based riverine groups and the estuarine/coastal groups. The principal conclusion from both groups was that the broad-scale hydrodynamic and geomorphological drivers of ecosystem change can be simulated now or will be available in the near future. There is however some concern from the author that the outputs from the hydrodynamics and geomorphology in CFMPs and potentially CHaMPs (and also SMPs with no CHaMP application) may not have sufficient spatial and temporal resolution to allow ecosystem impact assessment at this time. Further research was commissioned to investigate this assertion as part of the study to determine the hydrodynamic and geomorphological input datasets and platforms on which to base ecosystem modelling tools, which is reported in Section 4.3.

Ecosystem Modelling Platforms

Both groups considered that there were no ecosystem models that can suitably simulate ecosystem change over the broad geographic scale either in the short term and particularly over longer timescales. The extrapolation and interpolation of short term datasets for longer periods inevitably leads to reduced confidence in the modelled outputs, which is exacerbated by the lack of clear understanding of the biological linkages and processes. This mirrors the findings of a previous project carried out for English Nature on the role of ecosystem models to predict the effect of one stressor, nutrient enrichment (Read *et al*, 2001). The study concluded that while there are good conceptual models and, in some cases detailed models, there were a lack of suitable data and case studies to validate these.

A large number of modelling types and approaches have been identified for river catchment ecological modelling, although none have proved appropriate for BSEIM. Several of the models appear to have developed a number of the required process interactions that could be used to inform model development (eg. macrophyte; phytoplankton; salmonid process variables). The coastal group considered that all ecosystem models currently under development are largely research-based and will require significant additional development before considered sufficiently robust. The ERP2 programme, as discussed in Section 4.8, may help in this regard (French *et al*, 2002). A common theme was the recognition that the next generation of predictive models should have a geographically referenced component, if possible harnessing the use of a consistent GIS database format and potentially using remote sensing techniques to gather broad-scale ecosystem data. This approach has been investigated by a variety of workers and would appear to be a viable technology.

Data Sources

Sources and the quality of existing data were highlighted as a specific problem. There is no co-ordinated database that describes the ecosystems of catchments or in the coastal zone, although there are many data for both areas. A key problem is that there has been no systematic monitoring and data collation programme for the purpose of ecosystem impact assessment. RIVPACS (macroinvertebrate), RHS, Mean Trophic Rank (MTR - macrophyte) and NMMP (National Marine Monitoring Plan - for benthos) datasets will be of some use although each of these concentrates on single components of the ecosystem. The RIVPACS and recently-developed coastal version COASTPACS (IECS, University of Hull) are descriptive and predictive multivariate models which link freshwater and marine benthic data respectively to environmental variables. It is of note that both of these approaches required quality-controlled, standardised and accredited biological data which, in the case of RIVPACS, were collected especially for the development of the model. As such, the lack of sufficiently good quality ecosystem data of the required resolution and for all ecosystem components is likely to restrict BSEIM in the short to medium term. Methodologies should be developed that can deal with the lack of spatial resolution in base data, which may mean that lower resolution less complex models may be the most suitable option, particularly in the short term.

BSEIM tools will clearly have to sit within the present framework of existing data availability, the technical abilities of the user groups and resource constraints (funding, time for studies etc.). The range of tools should reflect these factors and be amenable to uptake at a variety of scales and complexities.

User Focus

Development of the tools should reflect user needs, with immediate specification of a suite of more basic information and predictive tools, and a more fundamental ecosystem modelling platform and modules to follow in the medium to long term. Audit and post-scheme appraisal were specified by both groups as important considerations in the development and iteration of BSEIM tools, allowing comparison of predictive outputs with actual outcomes. Given the broad-scale and long term horizons, these audits will be required over a long time series.

Packaging of the BSEIM tools and training to encourage full uptake are considered a key to the success of the R&D programme. The most suitable suite of tools is likely to incorporate broad indices of change (diversity, rarity etc.) with more sophisticated quantitative models and a user-friendly decision-support system. Uptake of the BSEIM toolbox should be encouraged through outreach programmes similar to those pioneered by CIRIA on behalf of the construction industry.

Strategic Assessment and Dynamic Ecosystem Change

There remains a concern, having identified the user needs and the drivers of ecosystem change, that there are conflicting data requirements for the CFMP and CHaMP approaches and the needs of broad scale ecosystem impact modelling. It is likely that in the fullness of time there will be a need to predict impacts on a full range of natural and impacted ecosystem types. The workshop participants wanted to ensure that any BSEIM tools that are developed under the auspices of the flood and coastal development R&D programme are transferable and consistent with other research programmes and user needs. The Water Framework and Habitats Directives were specifically highlighted. With major drivers such as these Directives, ecosystem assessment is likely to focus in the near future more clearly on general ecosystem quality (eg. “good” ecological status) rather than solely/specifically the areas or reaches with nature conservation designations.

This research should therefore embrace the concept of protection and enhancement of dynamic evolution within all ecosystem types. To achieve this goal, there will need to be a gradual move towards more holistic and integrated modelling tools that can simulate long-term dynamic change in the environment and translate the implications to supported habitats, communities and species.

4 SCIENTIFIC BACKGROUND

4.1 Introduction

The BSEIM initiative follows recent trends towards modelling for policy purposes over the medium term (c. 100 years), by emphasising integration of process modelling and a broad spatial scale (i.e. that of regional-scale catchments/coastal zones). There is a research effort underpinning this (e.g., the LOIS and LOICZ programmes), and the climate-change response research community is emphasising integrated assessment models as a key user-oriented direction for research (cf the Tyndall Centre). Thus there is a broader context for this initiative.

Although there is an explicit requirement to develop integrated broad-scale models, this may initially be perceived as problematic, since the process content and data needs of the models required to simulate hydrogeomorphological-ecological linkages within different subsystems are likely to be thought difficult to integrate (especially in a usable IT-based decision-support system). For example, it is difficult to envisage a common modelling approach that can simultaneously satisfy the needs of simulation and prediction of the dynamics of, for example, hillslope runoff, diffuse pollution, buffer strips, river channels, aquatic ecology, floodplains and wet woodlands. However, the purpose of this report is to suggest a convergence of modelling strategies that might lend themselves to integrated models for impact analysis, and that retain the flexibility needed for nested models of varying resolution for impact assessment at different scales and in different subsystems (adaptive management).

4.2 General Principles

Dynamic ecosystem response to natural and/or anthropogenically induced change is a product of a number of complex physical, physico-chemical and biological interactions. Simulation of broad-scale change in ecosystem function must therefore encompass a relatively wide range of technical disciplines in order to achieve a viable prediction of the likely outcomes. Given the relative complexity, there is also a need to consider the confidence that can be attached to any prediction.

In order to adequately model ecosystem changes it is therefore necessary to have an ability to predict the changes caused by the drivers and then to model the cross-linkages between the physico-chemical and ecological processes. There are a number of factors that should be considered:

- Changes to physiographic character (e.g. basin shape, topography, bathymetry) which in turn will alter hydrodynamic function leading to variation in water flows, velocities and levels
- Consequent implications for sediment transport and changes to erosional/depositional/accreting character
- Potential impacts on habitat stability through for example direct effects of changes in flow character or substratum availability or indirect changes through water quality effects
- Consequent changes due to hydrographic alteration causing a change in food supply and/or the recruitment of colonising organisms

- Acute or chronic impacts on communities and species reliant on the ecosystem, ranging from macroalgae and benthos to birds, fish (spawning, nurseries and adult habitat) and possibly mammals.

To achieve a fully integrated ecosystem model, a number of components would ideally be necessary:

- Hydrodynamic submodel for space-time variation in water flows, velocities and levels
- Hydrogeomorphological submodel to simulate changes in channel form and sediment characteristics
- Hydrochemistry submodel for transport and transformation of key physico-chemical variables such as nutrients and sediments
- Hydrodynamic models predicting the delivery of key ecosystem components such as food or colonising/migrating organisms
- Lower trophic level submodels for primary, invertebrate and small "forage" fish production
- Population-dynamic submodels for key animal indicator species (usually individual based models, see Section 4.4.7) or at least age-size-space structured abundances.
- Successional submodels for changes in plant and animal community composition.

There are a large number of ecosystem types and biotopes associated with riverine, estuarine and coastal areas, as identified for example by the Marine Nature Conservation Review (MNCR) - Joint Nature Conservation Committee (JNCC) marine ecosystem work (JNCC, 2000) and by the Environment Agency through the river habitat survey initiative. The relative sensitivity of each is a function of the stability of the available habitats and the dynamic ecological equilibrium of the communities and species that rely on those habitats. Different ecosystems change and evolve at different rates; some are highly dynamic while others are very slow forming climax communities.

Clearly, changes to dynamic ecosystems are more easily reversed and therefore potentially less sensitive than those of established and mature climax communities. Similarly, changes due to anthropogenic activities may be more difficult to detect in highly variable environments, i.e. as a minor signal against a high background noise, or such changes may be absorbed more easily, i.e. environmental homeostasis (Elliott & Hemingway 2002). Highly variable estuarine environments are a particular example of these features. The above demonstrates the need to understand not only the driving mechanisms for ecosystem function (hydrodynamics and geomorphology) but also the composition and dynamic structure of the ecosystems themselves. Without knowledge of each it will not be possible to accurately predict impacts on ecosystems and their communities and species. Examples of flood management activities that may need to be modelled include:

- Set back (managed realignment) or abandonment of existing flood or coastal defences and consequent negative effects on previously protected wetlands and terrestrial systems.
- Increased use of managed realignment and the positive and negative implications for saltmarshes and coastal fringe.
- Inundation of previously protected or undisturbed coastal hinterland by sea level rise.

- Saline incursion into freshwater riverine and associated floodplain wetland habitat from sea level rise or change to flood defence structures.
- Constraining of river channels in the floodplain with consequent loss of dynamic equilibrium and associated wetlands.
- Potential damage by flood defence works to the ecological integrity of internationally important sites and sensitive ecosystems.
- Increased flooding frequency of undrained peatland habitats.
- Changes in inundation frequency in sacrificial flood storage areas.

At present there is no hydrological-geomorphological-ecosystem model developed that is close to linking the dynamic physical and biological processes, even for relatively simple processes like growth (Walters, 1997). Given this assertion, the following section reviews:

- Current hydro-geomorphological modelling approaches
- Current ecosystem modelling approaches
- Current operational model applications in the UK
- Existing ecosystem databases
- Complimentary existing and proposed R&D programmes.

4.3 Current Hydro-geomorphological Modelling Approaches

Generation of suitable input data from the hydro-geomorphological drivers is essential to the successful simulation of dynamic ecosystems.

This aspect is being considered within separate R&D programmes and are in some ways in a more advanced state of assessment than BSEIM. The key reports of interest are:

- Scoping the Broad Scale Modelling Hydrology Programme (Calver and Wheater, 2001)
- Estuarine Research Programme Phase 2 (French *et al*, 2002)
- Concerted Action on Fluvial, Estuarine and Coastal Processes (Mouchel, unpubl.)

Outputs from these studies demonstrate well the fundamental difficulties in the area of ecosystem modelling. The general thrust of the R&D programmes has rightly been the development of broad-scale tools to predict the impacts of flooding and coastal processes. However, when considering ecosystems and their supporting habitat and species, the resolution and range of the outputs can vary significantly. For example, to assess the relative change in a riverine wetland habitat it may be necessary to know the rate of change in flow, velocity, water level, wetted area and substrate type over a long timescale. The hydrological and geomorphological models being developed in these fora are not likely to be focused in this area, and particularly at this resolution, as these very detailed requirements are not necessarily a priority in terms of flood forecasting and management.

It is likely therefore that the outputs from these R&D programmes will be less than perfectly matched to the needs of BSEIM. The future modelling requirements for hydro-geomorphological data inputs to ecosystem are reviewed in the following Section.

4.3.1 Geomorphology as a Hydrological Boundary Condition

The land surface form of a drainage basin seems unlikely to change on a timescale of 100 years, but topography plays a key role in determining the spatial pattern of soil moisture, the distribution of runoff source areas, and the timing and time-distribution of catchment response to rainfall. This is because of the effects of contour curvature in plan, and slope curvature in section, on the routing and transmission of runoff, both surface and subsurface. The topographic/geomorphic control of hydrological behaviour has resulted in development of hydrological models, that use this control to underpin theoretical development of reduced-complexity but physically-based models. Such distributed models accommodate distributed input rainfall data and boundary condition soil data, and generate output which predicts soil moisture spatial patterns as well as streamflow, as demonstrated for example by TOPMODEL. The similarity assumptions greatly reduce computational complexity. These models can be used in continuous simulation mode to generate a flood frequency distribution, or as a driver for a linked water quality model. They are raster-based, versatile, and relatively simple to use and may link with other models (see below), to form an element of an integrated catchment modelling strategy which can be used in scenario testing and decision support. Further development would be required to adapt such models to simulate the transport (and deposit) of sediment. Nevertheless, this approach could also link with grid-based ecological models, and with agent-based ecological modelling in which the ecology is partly dependent on topographically-dependent moisture availability.

As well as predicting channel sources and the network structure from a catchment digital elevation model (DEM), it is possible to identify the reaches which have floodplains, and to use a rasterised approach to the simulation of overbank flows in these reaches. Routing of overbank floodplain flows across the topography of a floodplain can be undertaken using similar algorithms to those employed in routing hillslope flow. Bates and De Roo (2000) have shown that floodplain flow depths, velocities and inundation extents can be successfully simulated for extensive floodplain reaches using a raster-based model (LISFLOOD-FP), when compared with more complex Computational Fluid Dynamic (CFD) models. The raster model is parametrically simpler, but efficient in prediction terms (output quality relative to input parameter costs). Comparisons such as this are particularly valuable in supporting the case for using raster methods in the large-scale, long-term modelling required in the BSEIM project.

While the geomorphological boundary condition is likely to remain fixed over a 100-year time span, elements of the landscape may change. The valley fill, for example, may aggrade or be incised as the balance of sediment yield and runoff changes. In the latter case, floodplain may be converted into stable and infrequently-flooded terrace fragments on which ecological succession takes place without interruption. In parts of upland Britain (the Cairngorms, west Wales, the Howgill Fells), there is evidence of floodplain surfaces converted to terraces at about 100 years ago. It is thus of interest that landscape evolution models have now developed to the point where this kind of evolution can be simulated. The CHILD model (Tucker *et al*, 2001) and the CAESAR model (Coulthard *et al*, 2001) are examples. Such models can also be structured and run as raster-based models, or rasterised initial conditions can easily be redefined as Triangular Irregular Networks (TINs), which are alternative methods of topographic representation which have certain advantages over grid-based representations, because they can be fitted more smoothly to the topography, and provide a smoother surface for modelling flow and transport directions. Nevertheless, the point is that discretised, reduced complexity models of landscape change exist which can contribute to the development of a fully-integrated catchment-scale modelling system capable of simulating medium-term change.

4.3.2 Geomorphology as a Static Constraint in Ecological Models

Another context in which a raster-based modelling strategy has been employed is in population modelling. The classic dynamical population model, the predator-prey model, is essentially aspatial, or at least it runs at a spatial scale where the population processes can be treated in the aggregate. Spatially-explicit population dynamics models in a raster form can examine the relationship between predator foraging behaviour and the spatial patchiness of prey. This patchiness represents the metapopulation structure, but also takes note of the effects of environmental constraints, such as topography, land use, and barriers to migration such as lakes and mountains. Examples of this are provided by Sherratt *et al* (2000, 2002). In the first of these, a cellular automata model suggests that vole population dynamics in Kielder Forest are dependent on the occurrence of clear-felled patches and migration distances. The second suggests that the forms and occurrence of travelling waves in the dynamics are strongly dependent on landscape barriers such as lakes; such waves may, indeed, only occur in the presence of these barriers. Insights such as this are very important in integrating the temporally and spatially patchy data derived from empirical studies, which could otherwise easily be misinterpreted.

This research demonstrates that the static elements of the geomorphological landscape impose significant influences on the population dynamics, and that accordingly the response of ecosystems to external forcing at the catchment scale cannot be modelled without a landscape-scale framework. However, at the same time the research indicates that a raster-based modelling approach provides a suitable integration of a DEM, a GIS-based storage of information on land use and topographic constraints, and models of hydrology and sediment production.

4.3.3 The Dynamics of Channel and Floodplain Development

Channel migration processes and the associated patterns of erosion and deposition construct the floodplain, and both the processes and the floodplain morphology and sedimentology differ between channel pattern types. A common distinction is between single-thread meandering and multi-thread braided rivers. Having classified channel pattern into one of these types, it is possible to use an existing model of the channel dynamics and floodplain evolution, and in each case raster-based modelling plays a significant role.

For braided rivers, Murray and Paola (1997) have developed a model which routes flow across a topographic surface according to the local gradient between grid cells, with simple algorithms for erosion and for sediment routing driven by the flow. Depending on the parameter combination, channels become locked in a particular path, or avulse intermittently into low points on the "floodplain" surface. This constitutes a reduced-complexity model, with highly simplified physics, implemented in raster form (see Section 4.5 for illustrative example). Thomas and Nicholas (2002) have used a similar raster-based method to simulate flow velocity vectors in braided rivers, and like Bates and De Roo (2001) at a larger scale, have shown that raster methods, with their reduced physical complexity and parsimonious parameterisation, produce results that compare very favourably with 2D computational fluid dynamics methods based on solution of the shallow water equations. In the case of meandering rivers, a mixed vector-raster model exists based on the work of Howard (1992). This defines the centre-line of the channel, and invokes a simplified cross-sectional model in order to represent the secondary circulation associated with bend curvature for the purposes of driving bank erosion and channel migration, with bend cut-off occurring at a threshold neck size. Overbank flows deposit sediment across a rasterised floodplain surface, and infill of hollows and general aggradation are both simulated.

In their basic forms these models both involve steady state flows, rather than variable flows to represent hydrographs. As a result, they have no true timescale, but generate change over successive iterations. However, modifications of both models permit the introduction of a true timescale, in which case the rates of change of the channel and floodplain are simulated. In addition, there is a disadvantage in having to select the model initially, according to the channel pattern expected; an important development would be to allow a combination of vector and raster elements in a composite model which would allow the evolution of either meandering or braiding according to the parameters defining rates of bank erosion and sediment transport. Thus, there is a need for research to develop this modelling approach further, but in principle the raster formulation is again available, for the reach scale within a drainage basin.

4.3.4 Geomorphology as a Dynamic Control of Habitat Diversity

Given a rasterised model of the floodplain elevation, surface age (time since formation, and time since last inundation) and even sedimentology, it is possible to conceive of a further link in the series of models, in which the habitat type and age produced by a channel-floodplain model drives a succession model (based on Cordes *et al*, 1997; Richards *et al*, 2002). In this simplest form, the succession is constructed empirically from the evidence derived in a particular case study. Such an empirical summary of succession is however tainted with the limitations of empiricism noted earlier. An alternative approach, which would again require a research effort, would be to develop an agent-based modelling approach (Deutschman *et al*, 1999; Gimblett, 2002) in which the agents (occupying cells on the floodplain surface) are either functional plant groups, or species (see also Section 4.5). One such group might include those species that form early colonisers of bare sand/gravel deposits on channel bars, another would be a young softwood community, another a dense hardwood. Defining functional groups avoids the complexity of treating every species separately (reducing computational demands), and permits development of a generic model structure applicable to different climatic regions where the species composition of functional groups would be locally contingent. However, in due course this modelling strategy could be refined to species level, with matrixes of species preferences and tolerances defining the probability of individuals occupying a model cell.

The rules required by an agent-based model would include, for example, some form of statement about the preferences of given functional groups for a certain habitat type (with the habitat being generated by the channel-dynamics model). For example, a functional group of floodplain plants might generally occur in a particular elevation range above low water level, but the observed elevations for that group in a particular place might reflect the effects of substrate sedimentology, itself co-varying with elevation. Alternatively, the elevation might be a surrogate for another variable (such as flooding frequency) which is the real control variable. Given a set of rules, it will be possible to allow each cell to be occupied by an appropriate functional group. As the floodplain surface changes, the functional group in a cell will change, both by passing through a succession, and occasionally by being re-set by flooding or erosion. There is also an opportunity for the ecology to feedback into the processes causing channel migration and floodplain development, through its effect on bank erosion rates and floodplain flow resistance. Indeed, it is important that the ecological model should cause feedback into the geomorphological and hydrodynamic modelling, to affect how erosion and deposition occur, and to affect the nature of the flows (through vegetation roughness and its impact on flow and sedimentation), and the future development of the floodplain geomorphology. This will mean explicit coupling of the geomorphology and ecology at the reach scale within a catchment or coastal zone model.

This approach - a coupled model of hydrology, geomorphology and ecology - will offer the potential for sophisticated simulation of environmental management strategies. These might include restoration of floodplain woodland for the integrated, and often assumed contradictory goals, of enhancing biodiversity and achieving flood management. Wet woodland could be encouraged as floodwater storage zones in appropriately chosen stretches of floodplain, for example; and the choice of reach to be treated this could be evaluated in a series of model scenarios.

4.4 Current Ecosystem Modelling Approaches

4.4.1 Background

There are now many ecosystem and ecological modelling platforms that have been developed to simulate ecosystem effects, from a specific level through to generic broad-based system models. There is a correspondingly wide range of conceptual, empirical and mathematical types within the framework (see Appendix 4). The following section seeks to identify the types of modelling tools that have been developed and their applicability to the present flood management decision-making process.

With regard to BSEIM, there is clearly a need to consider the integration of modelling tools, as there are a number of factors that can only be adequately addressed by such development, including:

- The high level of complexity of ecological and environmental processes and decision problems
- Multiple scales of description (in time and space)
- Establishment of linkages between diverse model types (e.g. physical and ecological)
- Heterogeneity and quality/reliability of available datasets.

Numerous ecological modelling frameworks have been developed. Future modelling tools will be developed from one, or more likely a combination of these modelling frameworks.

4.4.2 Empirical Models

Several empirical models are available for prediction of ecosystem function, such as RIVPACS. These systems are usually based around the collection of baseline ecological data from a wide range of ecosystem and habitat types, followed by database development that seeks to identify “natural”, “typical” and “atypical” community structures based on the description of patterns and links between the biological and physico-chemical variables. The databases can then be used to type or predict what sort of communities should or could exist for given circumstances. Scores or indices are often associated with this type of modelling, such as LIFE or Habscore. The systems are reliant on good (both detailed and high quality) databases and are very useful for monitoring change over time. However, they have difficulty in predicting the effects of future changes – principally because it is often difficult to know what changes have already been manifest on the sites comprising the database and the environmental variables that have driven that ecosystem development. They may work on the basis of predicting the changes in the environmental variables and then use the magnitude of such change to indicate the nature of the biological change.

River Habitat Survey (RHS) may fit into this category, given its use to define relative levels of riverine habitat quality, although at present it is limited in the ecological connectivity of habitats with communities and species. Proposals are, however, being prepared that would lead to better integration of geomorphology, habitat availability and ecosystem function (Marc Naura, *pers. comm*.).

The methods tend to have a limited scale and have only a rudimentary conceptual-modelling component. There may however be scope for “scaling up” some general conclusions that can be drawn from intensive localised studies using scale-area curves and other statistical techniques. In the case of RIVPACS and COASTPACS, these are developed to cover the whole of the UK area based on large datasets.

Several multiple regression type models have been developed as an empirical basis for linking ecological parameters to the prevailing physico-chemical variables, based on large-scale datasets derived especially for the purpose. For example GEMBASE (General Ecosystem Model for the Bristol Channel and Severn Estuary) developed by the then IMER in Plymouth (Radford, 1991). At a lower level, Elliott & O’Reilly (1991) produced multiple regression models for the nearshore subtidal benthos and its links to the physical variables.

4.4.3 Dynamical Systems

These are the classical tools of ecological modelling. They are used to track species interactions over time, usually in a homogeneous (non-spatial) environment. The basic variables are population densities. They have been used to investigate all the basic ecological interactions: e.g. growth, competition, predation, parasitism. They are often parameterised using life-history data, biomass estimates, predation rates etc., though density-dependent factors can be problematic.

However, probabilistic dynamical systems can behave differently from corresponding deterministic models. It is often difficult to calibrate stochastic effects, and in certain types of system (e.g. predator-prey) stochastic effects can alter model behaviour radically.

Any type of sophisticated model is likely to include dynamical systems components at some level. For broad-scale strategic modelling, these should be kept as simple and schematic as possible, unless intricate connections to fast time-scale physical processes are required.

4.4.4 Proprietary Deterministic Mathematical Models

There are a number of proprietary deterministic mathematical models available that have started to investigate the links between hydrology, hydrodynamics, geomorphology and ecology. The models tend to be process driven, limited at this time to relatively simple simulations of phytoplankton through uptake of nutrients (and potentially shading). These include ISIS (HR Wallingford and Halcrow), Mike 11/21 (DHI) and Protech (CEH). Another approach established by the US EPA and marketed in the UK by CEH is PHABSIM, that uses river hydrodynamics and ecological habitat requirement to simulate changes in habitat availability, most commonly habitat for salmonids. All of these methods can be relatively data intensive and have not been applied in a broad-scale for catchment-based analysis. However, the possibility of further development of these platforms should not be overlooked and many of the lessons learnt can be usefully incorporated into the next generation of ecosystem models.

Examples are now emerging of a hybrid approach using the output from the more complex hydrodynamic models to determine flows, levels and wetted area, and then using either PHABSIM, as on the River Itchen (Dangerfield, *pers. comm.*) or fisheries productivity models, as on the River Eden (Conlan *et al*, 2002) to determine specific ecological impacts. Although tending to be rather community an/or species specific, these approaches should be further assessed and may prove to be suitable interim solutions for flood management analyses.

The EC has also commissioned a wide range of research into the fundamental and applied functioning of floodplains that should also be recognised. The EC IRMA-SPONGE programme has developed modelling approaches to the assessment of floodplain protection and biodiversity enhancement in large rivers that should be considered further. A recommendation for the next phase of this project is a better understanding of the many and varied EC funded research projects and their potential for integration into future initiatives.

4.4.5 Metapopulation Models

Metapopulation models are a very successful approach that has been widely applied (see, for example, Hanski and Gilpin, 1997, Hanski, 1998, Hanski, 1999). A landscape or region is conceived as a collection of patches of variable area, with each patch being (more-or-less) homogeneous, and patches linked through migration or other patch-to-patch contact processes. Within-patch dynamics for resident species is usually specified by simple rules (i.e. birth, death and growth processes; sometimes mutation). The total population of a species, summed over all patches, is known as a metapopulation, and is regarded as stable over a significant time scale (relative to the local within-patch subpopulations).

In a metapopulation model, the colonisation and extinction dynamics of the set of patches is more important for the persistence of the metapopulation than the within-patch dynamics. That is, once invaded, the carrying capacity of an individual patch is likely to be reached rapidly relative to the migration time scale.

This kind of model is most appropriate for species that are locally fragmented, with an intermediate degree of migration. If the migration rate is too high (of the same order as the within-patch population growth rate), then the metapopulation is essentially randomly mixed. If the migration rate is too low, then the separate patches are effectively isolated.

Metapopulation models have been used to study both single species and multi-species communities. For example, insights have been gained from this approach into species succession, species richness and composition, and the food web structure of communities.

This approach gives a simple, strategic representation of important processes at a large scale in terms of probabilities of persistence and colonisation and could be highly relevant to the tracking of indicator species at a large scale.

Good local data sets for key species are required and, in particular, data concerning the absence of a species from a potentially suitable local habitat, as well as its presence.

4.4.6 Cellular Automata (CAs)

These are the standard model type for explicitly spatial processes. A spatial domain is divided into a lattice of cells, each of which can be in a (usually fairly small) number of states. Updating of a cell's state depends on the states of neighbouring cells, and is governed by either deterministic or stochastic rules representing local ecological interactions. "Climatic" variables may be added which can have a more-or-less global extent. Of significance, this approach can be linked to GIS.

The ability to store a large number of state variables for each cell, and to update them on a relatively fast time scale is the key to the development of detailed landscape models. However, this is very data intensive, and very expensive, but is perhaps feasible, e.g. using remote-sensing data.

Drawbacks include: (1) selection of local rules is often problematic; (2) computational intensity limits the complexity and resolution of processes that can be modelled; (3) complex interaction rules can make emerging dynamic patterns difficult to interpret, especially if the rules are probabilistic; (4) sensitivity to the order in which rules are implemented; (5) sensitivity to the updating time step.

Spatial data calibration is very difficult as data are usually scarce and rarely match the spatial resolution required by models. This approach is of relevance as there is no real alternative for explicit spatial modelling. It is probably essential for linking hydrodynamic with ecological processes.

4.4.7 Individual-based Models (IBMs)

A computational approach to spatial modelling based on the behaviour of interacting 'individuals', whose states are specified by attributes. Included in an individual's state is its response to different environments and to other individuals. Space is modelled by cells that are either occupied or empty. The landscape is filled with a population of individuals who interact through contact processes within and between neighbouring cells. Time is updated in discrete steps.

The main drawbacks of IBMs are: (1) selection of attributes for individuals is often problematic; (2) computational intensity limits the number of individuals that can be modelled; (3) complex interaction rules can make emerging dynamic patterns difficult to interpret; (4) sensitivity to the order in which rules are implemented; (5) sensitivity to the updating time step.

IBMs have been extensively used to model plant monocultures, landscape heterogeneity, food webs, forest fire and gap dynamics, plankton dynamics, epidemiological processes, wading birds, the effects of smolt production for salmon in regulated rivers, various aspects of animal behaviour, and many other space-related phenomena (see, for example, DeAngelis and Gross (1992), Durrett and Levin (1994), Wolff (1994), Uchmanski and Grimm (1996), Jager *et al* (1997)).

Coupled map lattices (CMLs) are a variety of IBM based on a discretised spatio-temporal approximation of a reaction-diffusion equation. Each cell on a grid lattice represents a spatial location, with interaction between neighbouring locations represented by a finite-difference approximation of a spatial diffusion, and a within-node “reaction” term, representing the point-location dynamics, specified by an updating function. In this scenario, the local variables to be updated can have continuous values (e.g. biomass). CMLs have been used to model plant growth processes (Hendry *et al*, 1996), and also evolutionary and genetic processes.

Agent-based models (ABMs) are a related modelling approach, except that ‘agents’ are often more abstract entities than ‘individuals’ and can represent functional categories. Agents often respond only to specified event types, but can be capable of adaptation and learning. Several generic ecosystem modelling platforms use ABMs based on the SWARM system developed at the Santa Fe Institute.

It is difficult to assess the realism of these models as they are only as good as the local interaction rules built into them. They are probably best used for broad-scale scenario investigation, for example, to tell you that certain characteristic outcomes are likely, whereas others are very unlikely.

4.4.8 Conceptual Network Models

Flow network analysis can provide useful insights into ecosystem functioning. A network is a collection of nodes, pairs of which are joined by a collection of edges. Typically, nodes carry attributes, which may be quantitative or qualitative, indicating what features of an ecosystem they represent. Similarly, edges have both a direction, indicating which node is the source of an influence and which the recipient, and a parameter indicating the sign and/or the strength of the influence carried. If the network is dynamic, ‘strength’ parameters can represent flux rates (e.g. migration rates, or rates of material flow). If each edge represents a single, independent influence, then two nodes may be connected by multiple edges. Any such ecosystem representation can be ‘closed’ by introducing an additional node representing the ‘external world’, from which, and into which traffic can flow to and from internal nodes.

Trophic network descriptions of ecosystems are common, and useful for many purposes. The nodes are typically functional groups, such as detritivores or primary producers (plants), with edges representing flows of matter or energy between groups.

Ecosystem-oriented spatial landscape network models have been developed for a number of coastal areas and wetlands. Models for the Mississippi delta were used to predict the long-term habitat succession and horizontal material and water fluxes in relation to the costs and benefits of building levees (Costanza *et al*, 1988). The wetland models were successful in reproducing historical data for predicting the impacts of various long-term scenarios including sea-level rise and river diversion (Mitsch, 1988).

The Patuxent Landscape Model (Voinov *et al*, 1999) was designed to simulate fundamental ecological processes on the watershed scale, in interaction with land-use patterns. The model is based on a modified general ecosystem model that is replicated across a grid of cells that comprise the rasterised landscape. Different habitats and land use types translate into different parameter sets that are fed into the general model. The cells are linked by horizontal fluxes of material and information, driven mostly by hydrological flows. The authors assert that this approach provides flexibility in scaling up and down over a range of spatial resolutions, and is essential for tracking land use change. Rescaling experiments were performed to delimit the spatial sensitivity to various processes, and the results used to identify key factors.

Qualitative modelling of flows in a directed network can be useful in formalizing knowledge and integrating different processes where detailed long-term data do not exist. For example, this approach has been used to examine the impact of sea level rise on a (hypothetical) tidal inlet with two adjacent beaches and intertidal flats (Capobianco *et al*, 1999). In this example, influences between nodes are merely signed (+1 for a positive impact, -1for a negative impact or 0 for no impact).

Results from these types of qualitative network models can be refined by quantifying influences in more detail (e.g. Sanchez-Arcilla *et al*, 1996, Townend, 2000).

It seems likely that this kind of network approach could be developed much more extensively, in particular by introducing explicit dynamics (which may be stochastic). This would require a set of dynamic models of changes in both nodal attributes and influence parameters between nodes. For example, an impact could be cumulative over time (such as slowly rising sea level, or the impact of erosion/deposition dynamics, or an increased frequency of severe floods), with time lags, and perhaps threshold effects, mediating the downstream network pathways. Formulating such dynamic models will be a major challenge. Ideally, network formulation should be such that influences from one node to another are transmitted through linear, threshold or other simple functional responses. However, for dynamics, these responses should be formulated in terms of rates rather than absolute values (e.g. accumulation or dissipation rates).

A significant advantage of this type of modelling is that a single network model can accommodate several (hierarchical) layers of sophistication, depending on the degree of detail in the representation of sub-networks that is justified by the current knowledge of processes and the availability of relevant data. For example nodes and edges can be linked to more detailed dynamic models.

This approach may be highly relevant to broad-scale scenario conceptualisations and scenario investigations.

4.4.9 Bayesian or Belief Networks (BNs)

A Bayesian Network (BN) represents conditional probability dependencies between possible events (random variables) in the form of a graphical network. BNs are a marriage between probability theory and graph theory which originally arose out of an attempt to add probabilities to expert systems. Statisticians and the Artificial Intelligence (AI) community are very excited about this technology.

A complex system is built by combining simpler parts with probability theory providing the glue, ensuring that the system as a whole is consistent, and providing ways to interface models to data. The graph theoretic representation provides both an intuitively appealing interface by means of which highly-interacting sets of variables can be modelled, as well as a data structure that lends itself naturally to the design of efficient general-purpose algorithms. BNs can be extended to incorporate dynamics (Dynamic BNs, or DBNs), in which each time slice is a state of a BN.

The approach can be very flexible, in particular for representing systems that have unobserved components. It is claimed that in some circumstances BNs can be used to separate causality from correlation.

Data can be used in the context of a pre-existing model to make inferences about unobserved variables. In addition, data can also be used to construct an optimal (D)BN model when we are unsure what the model ought to be.

The approach is highly relevant to issues involving strategic uncertainty, but assumptions need to be made about appropriate variables and their probability distributions. BNs present a very promising potential approach to broad-scale modelling, which have as yet been insufficiently utilised in an ecological contexts.

4.5 Examples of Raster-Based Models with the Potential for Ecosystem Linkage

Having reviewed the available and potential modelling platforms it is instructive to consider a modelling framework that has the potential to deliver, in the longer term, the types of predictive output that the user community has requested. Although not suggested as the main or indeed only avenue of research, it seeks to demonstrate the rapidly evolving development of models in this field and their true future potential. The starting point for the example is a rasterised representation of catchment topography, in the form of a digital elevation model (Figure 4.1). This may have additional data for each grid cell stored in the form of a Geographical Information System, and for visualisation purposes, draped onto an image of the DEM. For this example the topographic index which forms the core concept of the TOPMODEL catchment runoff model (Beven and Kirkby, 1979) can be derived from the DEM, and the spatial distribution of the index can be used to identify the stream sources, the network structure, slope instability, floodplain reaches, and a range of other phenomena (Figure 4.2).

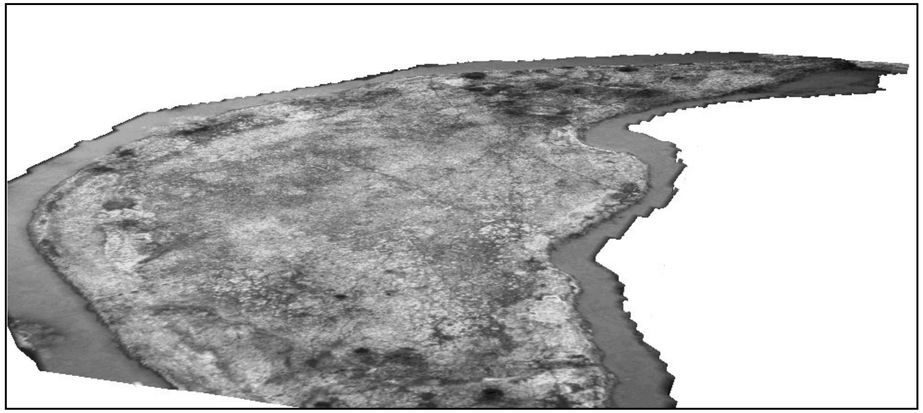


Figure 4.1: **An orthophotograph of an island in the floodplain of the River Ouse near Hemingford Grey, draped onto a Photogrammetrically derived digital elevation model of the floodplain.**

Figure 4.2: The topographic index (with soil transmissivity incorporated), and the locations of landslides in a small Nepalese catchment (after Brasington, J.)

In floodplain reaches the hydrographs generated by a grid-based runoff model for the upstream catchment can be routed downstream using a further rasterised method capable of simulating floodplain inundation, such as LISFLOOD-FP (Bates and De Roo, 2000). Figure 4.3 shows a time series of inundation extent predicted by a dynamic simulation using LISFLOOD-FP on a 25m resolution DEM for a 7 km reach (compared to an air-photo derived shoreline sampled at c. 160 h into the simulation). The topographic boundary condition of the DEM need not be regarded as a static condition, since models with a rectangular or triangular grid structure have been developed which simulate landscape evolution, including that of the valley fill; these include CHILD (Tucker *et al*, 2001) and CAESAR (Coulthard, 2001). Figure 4.4 shows an example of a CHILD simulation in valley/floodplain mode. Here a hypothetical valley system is shown after 5000 years of evolution, where changes in river base level have led to the formation, abandonment and partial erosion of two terraces. CAESAR is the Cellular Automaton Evolutionary Slope And River model. This is a gridded cellular model incorporating (at present) approximations for mass movement, soil creep, vegetation growth, hydrology, hydraulic routing and fluvial erosion and deposition over 11 grainsize fractions.

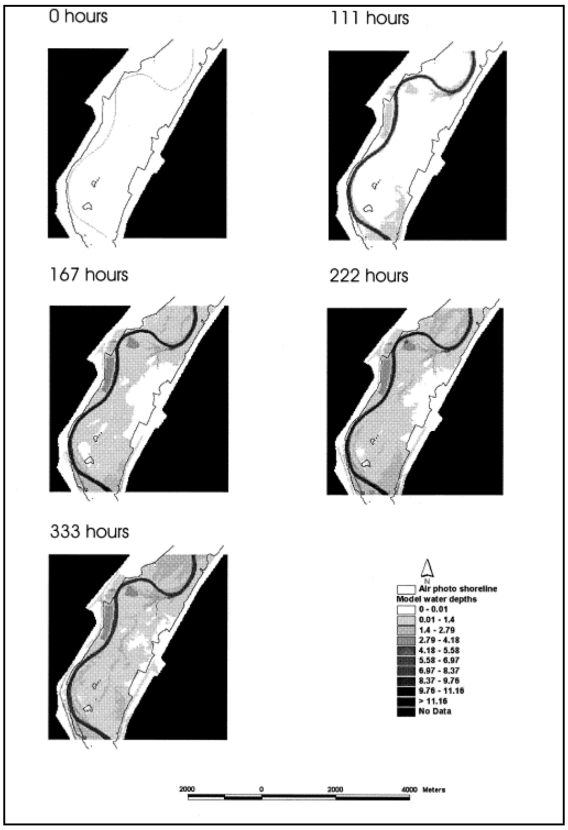


Figure 4.3: Floodplain inundation predicted by the raster-based model LISFLOOD-FP (after Bates and De Roo, 2000)

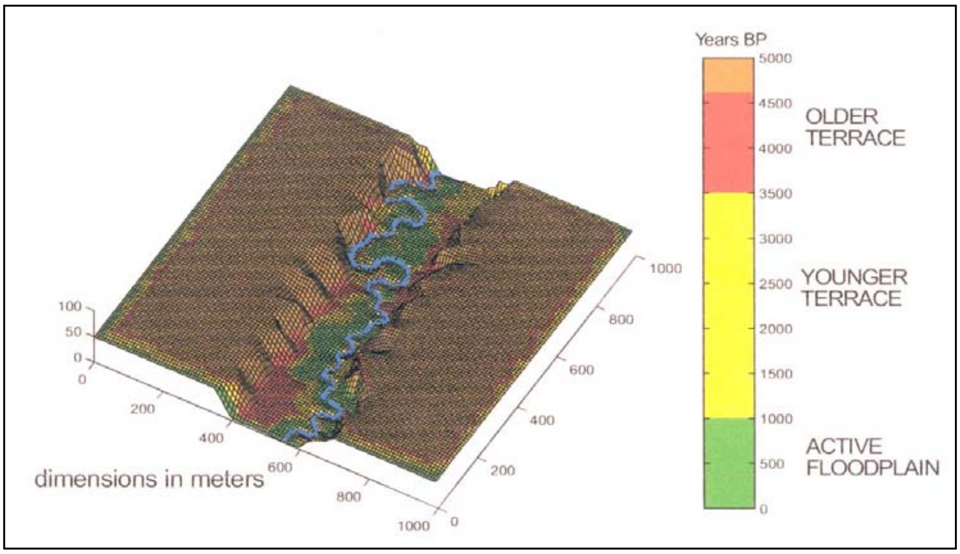


Figure 4.4: **Landscape evolution modelled using the CHILD model (after Tucker *et al*, 2001)**

Within a floodplain reach, the channel morphology may display considerable complexity, especially in braided river systems. Even at this scale, a grid-based model can successfully predict the distribution of flow amongst braided channels, and Figure 4.5 (Thomas and Nicholas, 2002) illustrates this by depicting water fluxes for a discharge of 20cumecs simulated by; (a) a raster model and (b) a depth-averaged CFD model. Arrow length is proportional to the unit discharge. The algorithm employed in this simulation is an improvement on that originally employed by Murray and Paola (1997) in their grid-based simulation of braided river dynamics. Figure 4.6 shows a run of this model in a reach of 22 x 400 cells, with a sinusoidally varying sediment feed having a period of 10,000 iterations (darker shades are lower elevations). The flow (and channel) pattern changes markedly between 135,000 and 475,000 iterations, implying that the surface includes cells which have been stable for different periods. In the case of meandering rivers, an alternative modelling framework currently exists (Howard, 1992), in which vector channel and raster floodplain elements are combined. Figure 4.7 shows a simulation for a freely meandering river, showing (a) contours of floodplain age in hundreds of iterations (areas older than 2100 iterations are bordered by dashed lines and uncontoured); and (b) contours of floodplain elevation are for a relatively low deposition rate (low elevation sloughs are shown by “S”). Integration of these two models is required so that *a priori* definition of pattern type is not required, and the model itself generates the pattern. This requires research, but will probably adopt Howard’s combination of a vector flow and transport model for the channel, and a raster erosion and deposition model for the floodplain.

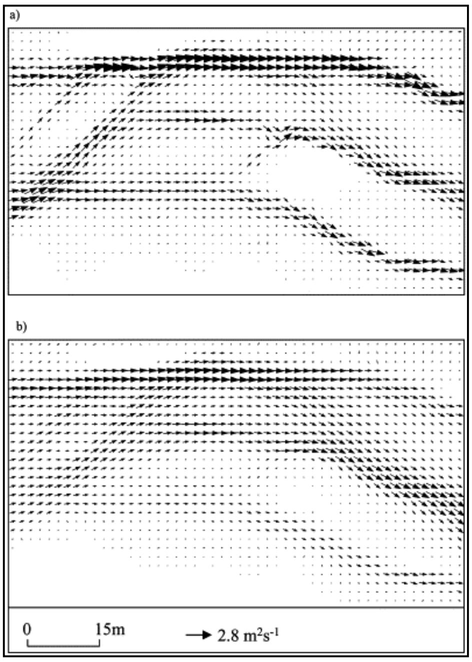


Figure 4.5: **A grid-based model of flow vectors in a braided river reach (a), compared to a depth-averaged CFD model prediction (after Thomas and Nicholas, 2002)**

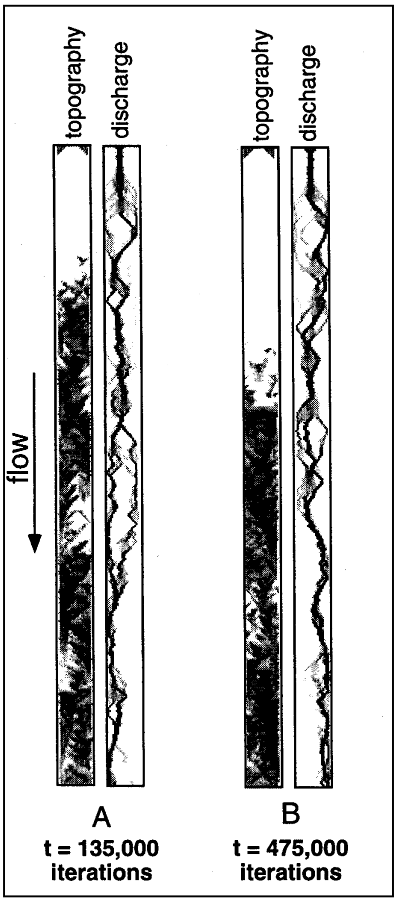
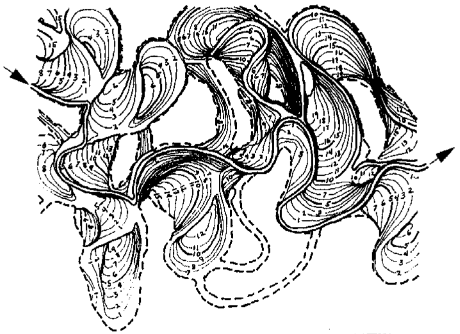
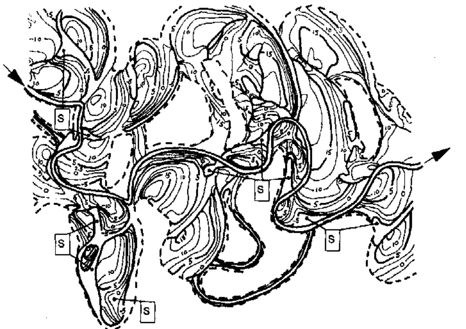


Figure 4.6: **The Murray and Paola (1997) grid-based simulation of the evolution of a braided river reach.**



(a) AGE (HUNDREDS OF ITERATIONS)



(b) ELEVATION - LOW OVERBANK DEPOSITION RATE

Figure 4.7: The Howard (1992) model of the evolution of a meandering river and its floodplain, based on a vector representation of the channel and a raster floodplain.

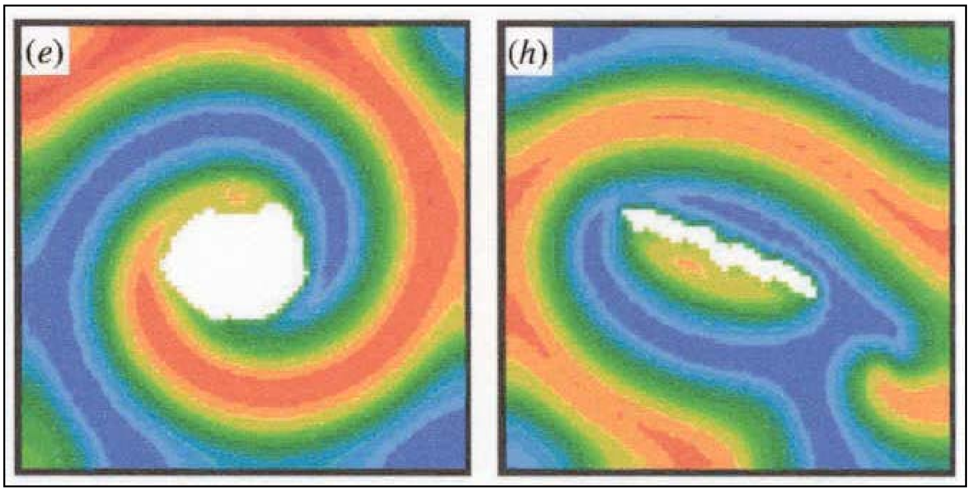
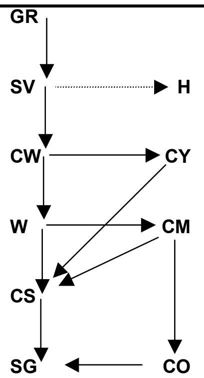


Figure 4.8: A snapshot of a travelling wave initiated in a prey population as a result of the interaction between predator-prey dynamics and migration in the vicinity of a topographic barrier (eg a lake) (after Sherratt *et al*, 2002).

The links between geomorphology and ecology involve the former in both static and dynamic senses. Firstly, topographic features in the landscape have been shown to influence the population dynamics in spatially-explicit predator-prey models (Sherratt *et al*, 2000, 2002). Figure 4.8 is the output of a coupled map lattice model of predator-prey dynamics, with densities in each cell driven by a standard predator-prey model, and by subsequent dispersal of individuals to adjacent cells. Individuals may "die", "deflect" or stay put at the edge of an obstacle. In the dynamic parts of the landscape, such as the floodplain, a combined form of the models illustrated in Figures 4.6 and 4.7 may be coupled to a succession model in which plant communities are defined by the age since formation, time since last flood inundation, elevation and substrate type of cells on the floodplain surface (Figure 4.9).

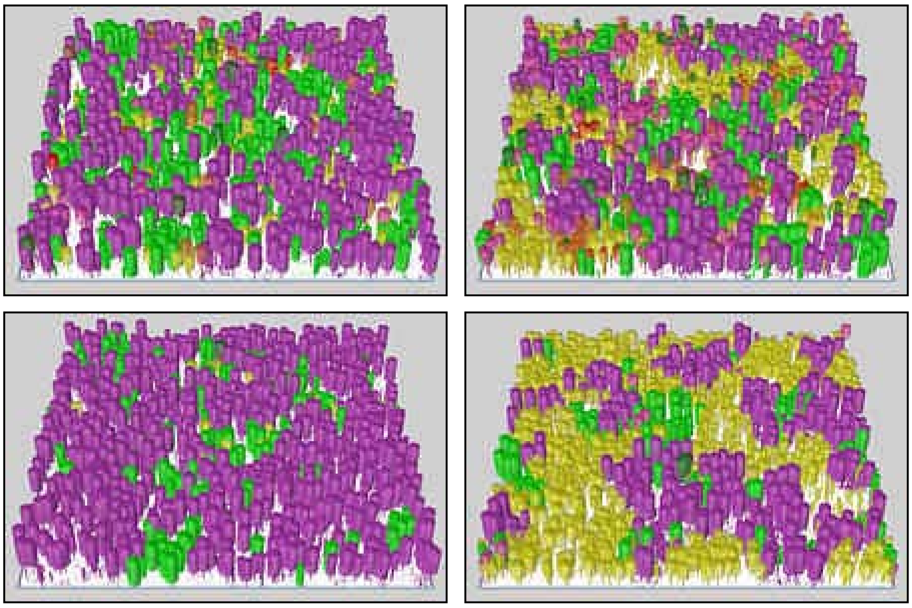
Height	Age	GR	SV	CW	W	CS	SG	CY	CM	CO	H
0.0		x									
0.2		x									
0.4		x									
0.6		x									
0.8		x									x
1.0	5.0	x	x								x
1.2			x								x
1.4				x							
1.6				x							
1.8	10.0			x							
2.0				x	x						
2.2					x	x		x	x		
2.4					x	x		x	x		
2.6					x	x			x		
2.8	40.0					x			x	x	
3.0						x			x	x	
3.2						x				x	
3.4						x				x	
3.6	100.0					x				x	
3.8							x			x	
4.0							x			x	
4.2							x				
4.4							x				
4.6							x				
4.8							x				
5.0							x				



		Height	Age
GR	Bare gravel	1.0	
SV	Poplar/willow seedlings on gra	1.2	5
CW	Willow saplings	1.8	10
W	Mature willow	2.4	30
CS	Cottonwood/poplar with shrub	3.2	80
CY	Young cottonwood	2.3	20
CM	Mature cottonwood	2.5	50
CO	Overmature cottonwood	3.6	120
SG	Shrubs and grassland	4.0	
H	Herbaceous wetlands	1.3	

Figure 4.9: **A succession model based on Cordes *et al* (1997) and Richards *et al* (2002); this kind of model could be coupled with those in Figures 4.6 and 4.7 to simulate ecological impacts of changing channel dynamics.**

Rule-driven, agent-based models of functional vegetation groups may be developed. These require generic rule-based associations between vegetation communities (or species) and the physical environment of cells; these would determine the changing community structure of the floodplain ecology. Ultimately, this kind of model can be individual-based, and simulates the dynamic interaction of species in different physical environments – as, for example, has been achieved for models of forest dynamics in the north-east U.S.A. Here, the effects of disturbance on the interaction between shade-tolerant and shade-intolerant trees has been graphically illustrated in Deutschman *et al* (1997). Disturbance opens gaps which are re-colonised by shade-intolerant species, so that over a 1000-year period of simulated dynamics, yellow birch is a more prominent species, whereas in the absence of disturbance, the diversity of forest is reduced and shade-tolerant beech is dominant (Figure 4.10). This can best be seen in the animations based on the model, at: http://www.sciencemag.org/feature/data/deutschman/base.htm .



Undisturbed Forest **Disturbed Forest**

Figure 4.10: Individual-based simulations of dynamics of forest in north-east USA (black cherry, white pine, red oak, beech, hemlock, and yellow birch) in response to light availability (after Deutschman *et al*, 1997). The rows are for simulations after 500 (top) and 1000 years.

Of course, finally, the evolving vegetation also feeds back to influence the hydrodynamic processes of flow, sediment transport and erosion and deposition, providing a full representation of the environmental properties (geomorphological, hydrological and ecological) and processes of a catchment, in a common modelling structure.

4.6 Current Operational Application in the UK

The ecosystem modelling platforms discussed in Sections 4.4 and 4.5 cover the full range of potential modelling approaches, from proprietary operational models to research-based mathematical concepts. However, it is also appropriate to consider the range of approaches that are currently available for application to existing CFMP and CHaMP ecosystem modelling.

4.6.1 Catchment-based Approaches

Riverine modelling tools for ecosystem assessment are relatively under-developed compared to their estuarine and coastal counterparts. There are a number of deterministic modelling platforms that are capable of catchment-scale hydrodynamic simulation, including for example ISIS and Mike11. Delft Hydraulics has also developed landscape/ecosystem simulation software although this is not thought to have been used in the UK to date. However, their application at such large scales is relatively untested. The main issue is the volume of data required to calibrate and verify the hydrodynamic modules. Following on, the geomorphological modules within these modelling platforms are relatively simplistic and lack resolution over the spatial and temporal scales required for long-term simulation.

Input data for catchment-scale ecosystem modelling are scarce. There are a number of approaches that can be applied in such circumstances. The most common approach in the CFMPs to date is to assess the rivers and identify sensitive reaches where changes to flood management practices may have the most impact. The reaches of concern can then be assessed in more detail, potentially using the more complex deterministic models described above.

To describe broad-scale ecosystem change, a range of input data and their predicted change over time are necessary:

- Flows, velocities, levels and wetted areas over suitable timescales
- Consequent influence on sediment transport and the erosional/depositional character of the river
- Implications of the geomorphological changes on habitat availability

From these building blocks it would then be possible to start to tease out the interaction of the ecosystem with the predicted changes in the habitat variables. In most cases where this level of data can be provided, the assessment has then reverted to the application of qualified expert judgement. For example, knowing that habitat will be lost or that inundation patterns may change, the expert can predict the likely ecosystem response. However, in many cases the basic scientific understanding of the dynamics and drivers for ecosystem function and change may be poorly understood and therefore only superficially estimated.

Other methodologies can be applied at this stage, including PHABSIM-type approaches using knowledge of hydrodynamic change and habitat preferences of certain species that can aid the subsequent determination of potential changes in population structure or integrity. These approaches tend to be require reasonable amounts of data and do not tend to represent the whole ecosystem. They may however be appropriate in certain circumstances where particular sensitivities are pronounced, for example in areas of salmon spawning. There are a number of drawbacks that would need to be considered if using such an approach (see for example Holm *et al*, 2001; Williams, 2001).

In summary, however, there are presently a number of fundamental difficulties with the application of ecosystem models to freshwaters, including the direct and indirect influence of hydrodynamic, geomorphological and physico-chemical processes on ecosystem function. Further work is required in each of these areas, some of which is already underway (see Section 4.8), with recommendations for BSEIM R&D described in Section 5.

4.6.2 Estuarine and Coastal Approaches

Over the course of the past 25-30 years a number of “ecological” numerical models have been developed and applied to a range of aquatic systems. Some have been no more than modules, representing algal growth dynamics, for example, incorporated into hydrodynamic/water quality modelling systems to investigate phenomena such as eutrophication. Others, however, have comprised complicated sets of algorithms representing aspects of ecology such as benthic invertebrate and fish population biology and the interactions between them and key physical forcing functions.

In attempting to integrate a wide range of diverse physical, chemical and biological processes these models have needed to develop relatively simple representations in acknowledgement of the limits of computing power available at the time and the need for ever increasing amounts of calibration and validation data. Moreover, once verified, calibrated and validated for a given site, these models required major re-configuration before they could be employed elsewhere.

In contrast, hydrodynamic and physical transport models are based on fundamental laws of conservation of mass and momentum and, once developed, are much more readily employed across a range of situations. These modelling tools are now sophisticated and able to provide relatively precise predictions of key physical drivers such as current regime, wave climate, bed shear stress and water level. They can readily be employed to assess the impact of specific flood defence works on these parameters at a local level or the likely effects of climate change/sea level rise on these parameters on a more broad scale.

For example, emphasis has been placed on the development of models to predict coastal erosion (for coastal protection purposes), coastal water quality (EC Directives on wastewater quality) and more recently habitat integrity (SAC designation). Two-dimensional hydrodynamic models such as Telemac, DIVAST and Mike21 are now capable of relatively complex and long timescale simulation at adequate resolution and with reasonable confidence intervals. Representation of sedimentary processes and changes to coastal erosion/depositional character are less well resolved, as discussed for example in the Estuary Research Programme (French *et al*, 2002). However, the R&D programme being developed should bridge the gap.

For coastal areas, the geomorphological models currently being used are more qualitative, focusing on the plan form of coastlines. Nevertheless it should still be possible to use such information to derive the required inputs for ecological models, although the uncertainties associated with such models may be greater (see also Section 4.8.2).

While some of the physical information likely to be required can be derived from top-down morphological models, other physical parameters that can be important in structuring habitats and species at a systems level (such as salinity, bed shear stress and current velocity) would need to be predicted from bottom-up hydrodynamic/sediment transport process models. The current resolution of such process models is probably adequate for generating the required broad scale predictions of key physical processes and the levels of uncertainty associated with those predictions are generally smaller than for the long-term morphological models.

At smaller spatial and temporal scales biological parameters, such as predation and competition for resources (food, space and light), have also been shown to be important in structuring habitats and species assemblages (Barnes and Hughes, 1982). Some biological interactions, such as the role of saltmarshes as sediment sinks can be important in influencing morphological development at a systems level. Biological processes have also been shown to modify sediment erosion at the sub-system scale, for example, the role of deposit feeders in promoting bioerosion and the presence of diatom and bacterial films in promoting biostabilisation (Wood and Widdows, 2002).

The extent to which biological processes are important in influencing morphological development of coasts and estuaries remains a key uncertainty. For certain elements, such as saltmarsh, the importance is already established and the Broad Scale Modelling Theme is commissioning research to develop long-term models of saltmarsh development that can be incorporated within system morphological models. However, for other biological processes, further research is required on their contribution to long-term morphological change. Some aspects of this issue are likely to be funded through the Estuary Processes Theme and the Sediment and Habitats Concerted Action but it is likely that additional research requirements will be identified during testing of broad scale modelling outputs.

It must also be recognised that our current scientific understanding of the importance of some physical parameters in determining ecological structure and function is incomplete. It is possible that during model development, additional requirements for spatial prediction of physical parameters may emerge.

Modelling of certain specific estuarine and coastal habitat and community change is relatively well developed. There have been a number of test sites, including Tollesbury and the Essex Marshes, that have been extensively monitored and studied to elucidate some of the mechanisms and processes involved in ecosystem change. The dynamic interactions resulting from the significant changes to coastal processes that occur through managed retreat etc. are now relatively well understood. However, the number of ecosystems where this knowledge has been accumulated is still relatively sparse compared to the total number of ecosystem types represented along the coasts and in the estuaries of the UK.

There are extensive data sets and monitoring programmes for the marine and estuarine environments, for example the National Marine Monitoring Plan and the Marine Nature Conservation Review Biotope creation (Connor *et al*, 2001). These have produced good linkages between the biotic and environmental variables. The data and the relationships and processes that have been determined are already used to inform the semi-quantitative assessment of ecosystem change

Much more could also be achieved towards the goals of BSEIM if predictive physical process models were more widely used to simulate potential physical change on a broad scale. The predictions obtained could then be employed by ecologists to predict likely ecological impacts in the light of existing knowledge of the limits of tolerance of aquatic biota to variations in these physical parameters. The reason why this is not done more at present may be that ecologists are largely unaware of the existence and capabilities of these powerful tools for simulating and predicting physical processes, together with the costs for developing the modelling outputs.

The general consensus at the BSEIM workshop was that hydrodynamic and geomorphological models and tools are now available or would soon be developed that could provide a suitable level of data for support to ecosystem assessment. The next step is therefore to develop the ecosystem assessment tools to take the process to its logical conclusion. Should such an approach be adopted, it is to be hoped that, ultimately, predictive physical process models will form the basic platform onto which numerical representations of ecological functions could be built in a modular manner to provide a seamless predictive tool for ecosystem impact modelling. It is likely that this will have to be resolved spatially within a GIS-based, distributed framework.

4.7 Existing Ecosystem Data Sources

4.7.1 Baseline Data

There are few consolidated sources of data for all features of the ecosystems present in fluvial, estuarine and coastal areas in the UK. There are however a number of institutions that are currently developing databases to better collect and collate the significant volumes of data that are being developed. Ecosystem data are being collected for a wide variety of purposes by a similarly diverse group of individuals and organisations, including for example, but not exclusively:

- Defra Marine Monitoring Group
- Agency laboratories
- Environment Agency, Scottish Environment Protection Agency, Environment and Heritage Service (Department of the Environment, Northern Ireland)
- English Nature, Countryside Council for Wales, Scottish Natural Heritage
- NERC and Higher Education Institutes
- Local authorities
- Wildlife Trusts and biodiversity networks
- Water companies and authorities
- Developers and industries
- Environmental and engineering consultancies
- Other local interest groups

Methodologies for ecosystem monitoring are becoming more standardised for both freshwater and marine systems. In all environments there are some components which have a large and well-developed data base, e.g. the benthos in freshwaters, estuaries and coastal areas, fish in freshwaters and estuaries, and vegetation in all areas. However, for the majority of the rivers and coastal systems in the UK there are not sufficient existing data on all components of the ecosystems on which to base a robust broad-scale ecosystem assessment.

4.7.2 Drivers and Processes Influencing Habitat, Community and Species Dynamics

A wide range of wetland and aquatic habitats, communities and species are influenced by flood and coastal management policies. At present one of the key difficulties in ecosystem assessment is that practitioners do not have access to a consolidated database that describes the existing state of knowledge of the drivers for habitat changes and the fundamental ecological requirements of the sensitive communities and species. There are a number of existing sources of information, including for example:

- Water Level Requirements of Selected Plants and Animals (English Nature, 1997)
- UK Marine SAC project (LIFE funded) - sensitivity of identified habitats (www.ukmarinesac.org.uk)
- cSAC research of "favourable conservation status" by the Environment Agency and English Nature (eg. Life in UK Rivers: www.english-nature.org.uk/lifeinukrivers)
- Individual reports to support EIAs, such as Environmentally Sustainable Management of the Water Resources of the Lower Derwent Valley: Ecological

Requirements of Key Features (series of unpublished reports for Yorkshire Water (Hammond, 1998))
- GIS databases being developed for the derivation and testing of typologies for freshwaters, transitional waters and coastal areas for the implementation of the EU Water Framework Directive (UK/Ireland Water Framework Directive Technical Advisory Group)

A collated database is required that provides basic information on the wetland and/or aquatic requirements of all habitats, communities and species of significance to flood management planning. There are a number of initiatives in this regard that could form the basis of the collation exercise, including the following:

- Marlin/MBA database for estuarine and coastal systems
- Marine Stewardship database
- OceanNet
- CoastBase (EU funded coastal and marine database)
- Environment Agency database (National Centre for Environmental Data and Surveillance)
- JNCC and English Nature databases (especially the MNCR database)

In the first instance the collation exercise should take the approach of describing the location of the data sources, rather than trying to assimilate them, and thus producing metadata. However, in the fullness of time it would be of great value to have a depository of collated data for both marine and freshwaters in a central location. This would preferably be geographically referenced and available for inclusion in GIS format.

In many cases suitable data may not be available and will require new surveying, monitoring and research. This is likely to be a time consuming and relatively costly exercise and should therefore be programmed to place an emphasis on the key sensitivities, in terms of habitats, communities and species (including key lifestages) that may be particularly susceptible to perturbations in wetland or aquatic systems. The research would therefore need to be focused and will require scoping, but should include:

- cSAC habitats, communities and species where not already subject to investigation through English Nature and Environment Agency R&D projects
- Key indicator habitats, communities and species indicative of impacts from changes in flood management practices (these will need to be established).

The data should ideally include information on the drivers and processes that determine the dynamic balance of habitat, community and/or species succession. These may include changes to river flow, velocity, level, sediment characteristics, availability of habitat at different lifestages, specific water quality, density dependent interaction with the same or other competing species etc. The derived data should be in a form that allows qualitative or semi-quantitative assessment of changes in river and coastal function on the key ecosystems. It is of note that the implementation of the EU Water Framework Directive, in producing classification systems, deriving and biologically checking the typologies and determining quality status, will necessitate the collation and analysis of relevant data.

4.7.3 Model Calibration and Verification Data

Much of the time and effort involved in developing spatially referenced and process-based models is likely to be devoted to calibration and testing against known data sets. The basic features of calibration are:

- The calibration reference data set
- The calibration criteria, expressed as a definition of the objective function to be used for optimisation
- The names and ranges of the parameters the modeller wants calibrated.

An initial model represents an initial set of hypotheses. Calibration is an iterative process, which can also involve model refinement, and proceeds by comparing model predictions against the reference data. Discrepancies are then evaluated via the objective function and, if necessary, new hypotheses developed to account for these (change the model), and/or existing parameters are recalibrated.

Sensitivity analysis is important to identify key influences and to assess the effect of stochastic variability.

Scaling: Even though drainage basins can be broken down hierarchically into smaller catchments, scaling up from intensive catchment studies is not a linear additive process. Management of water over large drainage basins must synthesise data from intensive experimental studies on a few watersheds by extrapolating important generalisations to larger drainages using modelling techniques combined with broad-scale data (usually sparse, and perhaps only qualitative).

Coupling: In most ecosystem models, “outside influences” (e.g. physical environmental or socio-economic factors) are introduced in the form of scenarios or forcing functions. Coupled independent models are better because they can explore dynamic feedback effects. The means of coupling independently developed models representing conceptually distinct processes is a major issue and one that will need to be addressed in the future.

The provision of a suitable dataset for calibration and verification of the ecosystem model is central to development process. BSEIM tools must be developed that can be calibrated and verified where necessary using an appropriate and not disproportionate level of data. In effect, for larger catchments the range of modelling that may be appropriate may be dictated by data availability and the need for calibration data.

4.8 Complimentary Existing and Proposed R&D Programmes

A number of government agencies, research and academic institutions and UK Water Industry Research (UKWIR) are currently undertaking complimentary or parallel research that may be of relevance to BSEIM. The following is a brief summary of the main project areas being progressed at present, although should not be treated as exhaustive.

4.8.1 Defra and Environment Agency Flood and Coastal Defence R&D Programme

There are a number of other initiatives that are complimentary or run parallel to the BSEIM project within the Flood and Coastal Defence R&D programme. The differentiation of the projects is usually by Theme, with the greatest level of integration between Broad Scale Modelling, within which BSEIM sits, and the Fluvial, Estuarine and Coastal Process Theme co-ordinated by Mouchel. The majority of the research to date has focused on the areas of hydrology and hydrodynamics, with geomorphology emerging as a significant research topic. Clearly, these issues are of great importance to the development of ecosystem models and tools. The outputs from these research projects may inform the direction and potential for integration of the physical and ecological components. Table 4.1 identifies the existing and proposed research in the BSM, Policy Development and Processes Themes.

The key areas of research that may link to BSEIM are highlighted in grey shading in the table. These include ecological process and successional information derived from the Tollesbury and Freiston trials, and potentially from the river morphology and habitats impact assessment. The other research is likely to be more peripheral.

Table 4.1 Existing and Proposed R&D in the BSM, Policy and Processes Themes

Fluvial, Estuarine and Coastal Processes Theme
Estuary morphology - survey and modelling for managed set- back site
Additional monitoring at the Tollesbury site
Development of predictive tools and design guidance for mixed beaches - stage 2
Estuaries Research Programme – Processes Component Phase 2
Sediments and Habitats Concerted Action
Flood Hydrology Concerted Action
Coastal Concerted Action
Freiston Managed Realignment
Sand transport and morphology of offshore sand mining or borrow pits/areas (SANDPIT)
Revitalisation of the FSR/FEH Rainfall Run-off Method
Guidebook of Applied Fluvial Geomorphology
Impact of Recent Floods on River Morphology and Habitats
Evaluation of breach processes at Porlock shingle ridge
Policy Development Theme
Up-dating and modernising the “Yellow/Blue/Red Manuals” for appraising coastal defence and flood alleviation works
Prediction of Future Coastal Evolution for SMP Review
Proposed Scheme Prioritisation System Review Project
The appraisal of human related intangible impacts of flooding
Improving Public Awareness and understanding about flood risk
Implementing Managed Realignment as a Strategic Flood and Coastal Defence option
Consistent Standards of Flood Defence for Flood Cells
Flood Plain Management Manual Phase 1
Testing the criteria for the designation of heavily modified waters for the Water Framework Directive
Wise use of Wetlands
National Environmental Assessment Handbook Update
Assessing the costs and benefits of flood defence
Broad Scale Modelling Theme
Estuary Research Programme – Tidal River Bathymetry (Humber)
Generation of Spatially Consistent Rainfall Data – Refinement and Testing of Simplified Models
Whole catchment modelling – scoping study
Improved methods for national spatial-temporal rainfall and evaporation modelling
National river catchment flood frequency method using continuous simulation
Development of estuary morphological models
Estuaries Research Programme Phase 2 – Take-up study from Phase 1
Socio-economic impact modelling – scoping study
Advanced hydraulic modelling tools scoping study
Evaluation of the SIMCOAST expert system for estuary management
Demonstration system for broad scale modelling tools and decision support systems for flood defence planning

4.8.2 Estuaries Research Programme and Futurecoast Study

The Estuaries Research Programme has been developed over a number of years under the auspices of the EMPHASYS (Estuarine Morphology and Processes Holistic Assessment System) consortium, funded by MAFF, Environment Agency, English Nature, NERC and EPSRC, and more recently by Defra.

The UK Estuaries Research Programme Phase 1 (ERP1) commenced in 1999 and was completed in 2000 (EMPHASYS Consortium 2000a). The final report from phase 1 covers the availability, application and limitations of predictive tools. A key point that has arisen out of ERP1 and other research is that, due to the uncertainty in the various techniques and the complexity of estuary systems, it is often necessary to synthesise the results of various techniques in order to produce a conceptual model for understanding the geomorphological system (Townend, 2002). Building from this understanding it becomes possible to explore "what-if?" scenarios for development and change. The modelling techniques investigated in ERP1 included top-down models, bottom-up models, and hybrid models. Some of these techniques can be applied to coastal areas. These approaches are explained in more detail below.

Top-down models can take two approaches: expert analysis or consideration of regime relationships. Expert analysis considers all the available data from various techniques and extrapolates these trends to form a prediction. The regime approach develops empirical relationships between the dimensional features of estuary shape and some measure of tidal flows (e.g. tidal volume and cross sectional area). Time series analysis allows checks to be made against past changes. Top down models are usually estuary wide and extend over long time periods (10-100-1000’s of years). Given appropriate inputs these types of models can be used to predict, for example, the position and size of habitats, composition of bed sediment, turbidity and sediment recycling, and areas of deposition and erosion.

Bottom-up models simulate the physical processes of estuary and coastal areas and rely on solving equations for water flow and sediment transport. Most of the approaches use finite element and finite difference grids. The models can be 1, 2 or 3D. Bottom-up models are used for short term predictions (days, weeks, months) and cannot readily be used for long term predictions because the errors accumulate from the repetitive iterations to dominate the outcome. Given appropriate inputs for bathymetry, existing grain size distributions and hydrodynamic factors, these the types of models can be used to predict bed sediment, recycling and erosion/deposition areas over short time scales.

Hybrid models are a combination of empirical top-down and regime models together with detailed bottom-up models. The general mode of operation is firstly to use the bottom-up model to generate hydrodynamic parameters and sometimes sediment concentrations. These are then used in regime theories, with volumetric or dimensional estimates derived from bathymetric data to explore the position of the system relative to a theoretical equilibrium state. Time series can then be carried out to explore whether the system is moving towards or away from this state. These types of models can be used to predict a wider range of parameters, including sediment characteristics and habitat availability.

The recommendations in ERP1 have been further developed by French *et al* (2002), and will be taken forward within the main Defra/EA Flood and Coast Defence Research

Themes, in particular, the Estuary Processes Theme and the Broad Scale Modelling Theme. The long-term goal is the development of models that can predict morphological evolution over large temporal scales (>10 years; EMPHASYS Consortium 2000b). Within the Broad Scale Modelling Theme, research will concentrate on the development of improved hybrid models which integrate top down understanding of whole system behaviour with more physically-based bottom-up models. Additional effort will focus on improving the linkage of hydrodynamic and morphodynamic models, developing models for subsystems (e.g. saltmarshes) and investigating threshold based concepts of equilibrium.

Table 4.2 is based on rationalisation of ERP1 recommendations, preliminary prioritisation of French & Townend (2001) and review of the ERP2 report. Shaded topics represent the research that may be of most relevance to BSEIM. Solid and open squares indicate strong and weak theme relevance respectively.

It must be stressed that not all of these studies have received funding and it should not be assumed that all will go ahead.

The emphasis is clearly on research to better understand hydrodynamic and geomorphological processes and modelling. Some research is earmarked for saltmarsh communities, which are of particular relevance to estuaries, but little community and species research is proposed.

The futurecoast study was commissioned by Defra and carried out by a team of consultants and researchers, over a period of approximately 21 months and finishing in May 2002 (Defra, 2002). The study provides predictions of coastal evolutionary tendencies around the open coast shorelines of England and Wales over the next century. The study was designed to assist the updating of SMPs and other Strategic Plans targeted at determining broad scale future coastal defence policy. The study considered the future shoreline evolution potential for each section of coast and an improved understanding of the coastal systems and their behavioural characteristics. The methodology developed in the project for assessing future coastal evolution involved the identification of change at three spatial scales: coastal behavioural systems, coastal behavioural units and geomorphological units. These predictions are essentially qualitative rather than quantitative. The predictions concentrate on future evolution of coast as plan form rather than majoring on the location of habitats. However, these predictions could be used to derive estimations of habitat extent and location.

Table 4.2 Research Priorities for Estuaries Research Programme Phase 2.

Research area (further rationalised)	BSM	Process	Engineering	NERC/EPSRC	Remarks
Improved bathymetric data	☐	☐	☐		Strategic need extends beyond ERP2
New estuarine time-series data	☐	☐		☐	Strategic need extends beyond ERP2
Spatial & temporal variability in sediment properties	☐	☐			Includes use of remote sensing
Sediment age-structure in case study estuaries	☐	☐		☐	
Hybrid model enhancement	☐	☐	☐	☐	
Formalisation/uptake of geomorphological approach	☐		☐		
Qualitative modelling – 'Futurecoast' for estuaries	☐				Link with SMPs and CFMPs
Limits to predictability of estuary morphology	☐	☐		☐	Required to support next-generation models
Inverse modelling techniques	☐	☐		☐	Priority for EPSRC funding
Ensemble forecasting techniques	☐	☐		☐	Priority for EPSRC funding
Evaluation of spatial landscape simulation approach	☐			☐	NERC funding: possible basis for future EMS
Critical testing of key geomorphological concepts	☐	☐		☐	Priority for NERC funding
Improved representation of intertidal areas	☐	☐		☐	
Methods for predicting extreme event interaction		☐		☐	
Estuarine wave processes and modelling		☐	☐	☐	Includes wave-current interaction
Tidal processes in complex morphologies		☐		☐	
Parameterisation of bottom up models		☐		☐	Turbulence, mixing, friction, sedim. transport
Behaviour of mixed sediments		☐			
Critical shear stress for real sediments		☐		☐	
Sediment-biota interactions		☐		☐	Link with Sediments-Habitats project FD1910
Mineralogy, geochemistry and sediment stability		☐		☐	
Sediment fingerprinting, tracing and budgeting				☐	Grainsize methods well-established
Saltmarsh management techniques		☐	☐		Need for update of Saltmarsh Manual
Compilation of socio-economic data sets	☐				Required for ERP3
New environmental valuation methods				☐	More relevant to ERP3
Prediction of future growth pressures	☐			☐	Required for ERP3
Interpretation/uptake/dissemination of existing R&D	☐	☐	☐		Need for links with other initiatives

4.8.3 Defra Marine R&D Programme

In association with flood and coastal defence planning, Defra also has an extensive coastal and marine R&D programme co-ordinated by the Marine and Land-based Inputs to the Sea (MLIS) division. There are a number of long term and/or broad-scale studies that are currently underway or planned that may have implications for the proposed BSEIM programme.

CEFAS, with funding from Defra, is undertaking a number of coastal and marine projects with an ecosystem monitoring component. These include the coastal observatory project, which has the potential to link water movement to ecology through remote sensing and ground truth observation, together with an assessment of the environmental impacts of marine dredging. The UK Hydrographic Office is also co-ordinating work to assimilate coastal baseline data, including ecosystem information, into a GIS format. Other information sources of potential use include the Marlin project at the Marine Biological Association, the Coast Map News newsletter (www.cefas.co.uk/coastmap) and the Marine Environmental Data Group at Glasgow University. In association with the scientific research, a key component of future research will be the dissemination of findings and a greater focus on user needs. Defra is sponsoring CIRIA to produce guidance on this aspect of the programme.

4.8.4 Environment Agency R&D Programme

The Environment Agency has a large R&D programme, some studies of which will be of significance to BSEIM. A list of existing R&D relating to habitats, communities and species is given as Appendix 5. The topics include, for example:

- Using RHS to derive habitat objectives
- Using RHS to develop habitat suitability models for cSAC species
- A number of fisheries studies relating to flow and habitat requirements
- Ecological studies of certain BAP species
- Relationship between flow and macroinvertebrates (LIFE)

Future funding should seek to ensure that any overlaps in the R&D programmes are synergistic and not run in parallel. In addition to the above, there are several initiatives linked to the implementation of the EU Water Framework Directive, for example the typologies and classification derivations and linkages to ecological quality.

4.8.5 English Nature

English Nature has co-ordinated a number of studies of significance to BSEIM. Life in UK Rivers is a 4 year EU LIFE funded project (until the end of 2003) that is developing approaches to the conservation of rivers that are designated as SACs as part of the Natura 2000 network. The project will produce:

- A handbook on the ecological requirements of river habitats and species listed in Annex II of the Directive
- A handbook for monitoring the conservation status of SAC rivers
- Techniques to address key issues affecting SAC rivers
- SAC river conservation strategies.

Seven rivers are being used as pilots for the EU LIFE funded project, including the Hampshire Avon, Afon Teifi, Eden, Endrick Water, Scottish West Highland Rivers. Several of the studies are complete and all should be available in the timescale of the BSEIM R&D programme.

A companion programme for the marine environment, the UK Marine SACs Project, has recently finished. The project has sought to provide management schemes for marine SACs through sharing best practice and gathering existing knowledge on the dynamics and sensitivity of marine features, such as *Zostera* spp., intertidal sand and mudflats, Maerl etc. These data will be of use in describing existing environments and their interactions. Several of the reports produced by the UK Marine SAC Project present conceptual models which indicate the linkages between the biological and environmental variables.

English Nature is also co-ordinating the Biodiversity Action Plan (BAP) process, including the prioritisation and development of the many of the plans themselves. Reports are available and work ongoing to support the BAP programme that may be usefully explored for the BSEIM database, particularly for freshwater and marine habitats and species.

With regard to modelling the ecological responses due to a particular stress, English Nature funded a study to assess the role and availability of models which describe and predict the effects of nutrients and organic enrichment in estuaries (Read *et al*, 2001). This study indicated the breadth of models available and included those which gave ecosystem responses to a single stress. While there were found to be many models available, there will be a limited ability for this information to be used in flood and coastal protection management.

4.8.6 NERC

The research councils have funded a number of water related topics in recent years that may have some benefit to BSEIM. These principally relate to the acquisition of field data through long term monitoring programmes such as the Land Ocean Interaction Study (LOIS). The LOIS output is now available and is particularly relevant for the hydrological, hydrodynamic and water quality data that were produced.

A large programme of work has also been developed under the titles of National Infrastructure For Catchment Hydrology Experiments (NICHE), Lowland Catchment Research (LOCAR) and Catchment Hydrology And Sustainable Management (CHASM). These programmes should establish a national infrastructure for catchment hydrology experiments for the UK research community that includes a research-based monitoring programme at the scale required for integrated catchment management. Three fully instrumented lowland catchments (LOCAR) and four upland catchments (CHASM) are being established. The framework will enable multidisciplinary research into the effects of anthropogenic impacts on hydrological and ecological regimes, biogeochemical cycling, hydrological performance of basins under future changing climatic conditions. The results of this research will not be available for some time but should contribute to the formulation of sustainable catchment management plans. The research is primarily focused on catchment hydrology and geomorphology, with less emphasis on ecosystem interactions. The inter-relationship between these studies and the BSEIM programme should be explored further.

In addition to the directly sponsored research, NERC also supports the research centres at Centre for Ecology and Hydrology, Proudman Oceanographic Laboratory and British Geological Survey. These institutes continue to develop ecosystem research that will be of direct relevance to the BSEIM programme.

4.8.7 UK Water Industry Research

UKWIR is the research arm of Water UK, the company representing the views of the UK water industry. Although the majority of the research is focused on operational matters relating to potable supply and wastewater treatment and disposal, there are research initiatives that may offer some commonality. UKWIR is currently funding the development of a catchment-based geographically referenced water quality model, the work being undertaken by a consortium led by Cascade Consulting and including the University of Leeds. The proposed open code hydrological platform and GIS-referenced land use component provide a framework that can be further developed to include hydrodynamic and ecosystem functionality that may have benefits for BSEIM toolbox development. The framework being developed fits well with that described for taking forward the catchment-based hydro-geomorphological component of a potential ecosystem modelling tool (see Section 4.5). Other climate change studies looking into the potential for changes in hydrology and river flows should also be considered.

5 FUTURE BSEIM R&D PROGRAMME

5.1 Introduction

The need to understand broad-scale effects on ecosystems is compelling, both from a regulatory perspective and also from societal pressures to mitigate anthropogenically-induced ecosystem damage. However, at this time the management tools to assess broad scale ecosystem impacts are poorly developed and relatively fragmented. To overcome this difficulty it will be necessary to develop a suite of tools, guidance and an appropriate package of training for the prospective user groups. This will require a phased programme of R&D over the next decade. To retain focus over such an extended timeframe it is useful to describe a vision of the preferred outcome, as described in Section 5.2.

In the short term, however, there is a pressing need to collate and disseminate best practice approaches in ecosystem assessment to support the practitioners in the flood and coastal protection user community.

The following section therefore seeks to determine an R&D programme that fulfils the long-term objectives whilst developing useful guidance in the short to medium term.

5.2 Vision

The objective is to produce a suite of catchment/coastal based modelling tools that incorporate geographically referenced land use information, hydrology and hydraulics, linked to sediment and geomorphological components that can simulate historic, existing and future driving functions. In turn, the models will allow prediction of natural and anthropogenic changes to ecosystem function and consequent ecological integrity.

The open architecture of the framework will allow use of the system and pre- and post-processed data in a consistent manner where the fundamental basis of the technology is internally consistent and agreed by all parties. The platform must also be consistent with other tools used to simulate inter-related water management activities (eg. Water Framework Directive, climate change etc.). The modelling platform must be adaptable to user needs and must support simulation of events and activities at a suitable spatial and temporal resolution. This will require a platform that has a number of operating modes, from simple low resolution simulation where data are sparse to more complex high resolution output where necessary.

It is recognised that such a bold vision will not be achieved overnight. There will need to be short, medium and long-term goals for provision of suitably robust predictive methodologies that are fit for purpose and readily available to the user community. Iteration of the R&D programme will be required at strategic milestones (2, 5 and 7.5 years) to ensure that the overall vision remains focused and deliverable. Developing expertise in catchment and coastal ecosystem modelling in the UK, Europe and more widely should be harnessed to achieve this objective.

An interim solution, pending development of the comprehensive model, should be the prediction of environmental physical/chemical changes. In turn these data can be used by experts to assess potential ecological change.

5.3 Proposed Strategy

The nature of this modelling strategy will require a successful solution to four key issues. Firstly, the strategy will have to be **flexible** enough to respond to the variety of questions posed (at different scales, and with differing degrees of interaction between modelled sub-systems). Secondly, the strategy will need to be relatively **user-friendly** if it is to form a decision-support system, implying a level of complexity below that of, for example, finite-element hydraulic models. Thirdly, and following from this, the tools employed will have to operate at the **lowest level of possible complexity** (for both parameters and data). Finally, the strategy will have to lend itself to the **visualisation** of model outputs that decision-support systems commonly require; this immediately implies that the use of a GIS framework for the storage, manipulation and display of data is likely to be required. Such a framework is also suggested by the availability of many relevant data sources in this form, especially raster sources such as remotely sensed imagery.

The second of the above issues is particularly critical because there may be a disjunction between current research activity and the modelling styles needed for decision support, which may lead to a need for additional targeted and strategic research. There is a parallel with climate modelling, where longer-term larger-scale modelling requires different kinds of model structures and emphases from short-term regional-scale modelling. The reduced complexity models and model components of the kind needed to couple hydrodynamics through sediment transport and morphological change to ecological responses at relatively large space-time scales are not immediately obvious, and the means of reducing 3-D physically-based models to lower dimensionality and simplified process representation, and at broad spatial scales, have not been a strong focus of recent research.

However, as will be evident from the discussion below, there is considerable potential for the development of a raster-based modelling framework of the interactions of geomorphology, hydrology, sediment transfer, channel dynamics and ecological change. Raster-based approaches immediately imply the role of GIS in data handling, and lend themselves readily to incorporation of data from remotely-sensed sources. They also subsume, or potentially subsume, several of the other methods employed in ecological modelling (cellular automata, mathematical dynamic systems models, metapopulation models). For example, dynamic systems models such as predator-prey models that run in discrete time can be made spatially-explicit so as to run in the discrete space of a raster framework. The question thus becomes less about the type of model, than about the resolution at which it is necessary to rasterise integrated sub-models in order to represent different processes adequately.

5.4 The Need for Integrated Ecosystem Modelling Tools

Two different kinds of philosophical reasoning support the case for integrated modelling; the first addressing the need for modelling, the second for integration. Firstly, as a basis for evaluating impacts of climate, catchment management and human interventions on the ecology of a drainage basin, models are necessary decision-support tools. This is particularly because of the limitations of empirical case-study evidence. Covariance amongst the properties of topography, soils, micro-climate, surface processes and ecology means that spatial sampling will commonly generate datasets in which the true nature of the control exercised over “dependent” variables by "independent" ones will never be clearly revealed. Individual case studies present unique combinations of circumstance, from which it is very difficult to generalise to other situations in the absence of an underlying model. Even in cases where large datasets are analysed statistically, the coefficients in regression-type models have no "physical" meaning, and are not strictly transferable. A common problem, too, is that a supposedly dynamic process, such as ecological succession, has to be inferred from the spatially-distributed pattern at a moment in time, which means that a technically invalid application of the ergodic hypothesis is required to convert from the spatial pattern to a temporal model.

Of course, it may be argued that some necessary components of an integrated framework for BSEIM are lacking at present, and that empirical evidence is all that exists. This is likely to be true in some areas, but if a suitably flexible overall model structure is adopted, and additional research is funded to develop the necessary new components to link with this structure, this weakness can in due course be overcome.

The second philosophical issue concerns the desirability within a catchment/coastal-scale modelling framework of an integration of hydrology, geomorphology, surface processes and ecology. It seems increasingly clear that conventional divisions of knowledge inhibit full understanding of environmental system function, and that inter-disciplinary approaches are necessary. Until recently most scientific enquiry has been discipline-specific, often limiting integrated assessment. However, climatic and land use changes impact upon drainage basin and coastal processes that range far more widely than single fields of enquiry. These processes are tightly interdependent, and display both direct and immediate impacts, and impacts that are delayed, secondary, and reflect indirect changes acting through correlated sub-systems.

For example, climatic change alters hydrology and sediment yield, and also changes the natural vegetation. However, a secondary vegetation impact on hydrology and sediment yield then occurs, and is compounded by the land use changes arising from the agricultural response to climate change. If the purpose of BSEIM is to explore scenarios of the interdependent impacts of climatic and human-induced change over time scales of the order of 100 years, the modelling needs to integrate the phenomena, ideally in a coupled manner which allows secondary feedback effects and relative time-scales of change in component sub-systems to be properly represented and assessed. At one level, therefore, geomorphology may appear to be a static boundary condition for the ecology, but at the same time, it represents a key hydrological control which influences spatial patterns of within-catchment response to external drivers. At another level, landscape elements such as floodplains may be sufficiently dynamic (given the necessary stream power) that geomorphological processes exert a major control over the dynamics of vegetation and the maintenance of biodiversity (Richards *et al*, 2002). Evolving vegetation may then itself influence the spatial pattern of channel and floodplain evolution, implying that explicitly coupled models are necessary to understand how to manage and intervene in the changing environment.

5.5 Overview of Ecosystem Modelling Tool Requirements

5.5.1 Introduction

The general conclusion from this review is that there is significant potential for reduced complexity modelling tools within a rasterised framework that can incorporate geomorphology, hydrology, ecology and their interactions, and integrate existing data sources and approaches. Such models have been shown in some areas (for example, flow vectors and inundation extent) to have predictive power comparable to more sophisticated models, and are parametrically simpler thereby lending themselves to larger-scale, longer-term simulation, and to their use as decision-support tools. Furthermore, there will be good opportunities to integrate the development of such modelling tools with data management systems such as the Modelling and Decision Support Framework developed to assist the creation of Catchment Flood Management Plans (see Evans *et al*, 2002; and http://www.mdsf.co.uk).

There seems no reason for concern about the degree to which this model structure can work for different sizes of catchment or coastal zone. There is obviously a nested hierarchy of basins, or coastal zones, and this may be an important issue in terms of policy and its implementation. Different scales may be appropriate for policy implementation for different issues (for example, medium-sized basins of a few 100s km^2 for water quality management though land use changes by farmers, larger ones for flood management).

One useful consequence of the grid-based approach to ecological modelling is that it is sufficiently flexible to handle ecological impacts at the scales of both “habitats” and “species”. However, it may initially help to focus the debate about conservation issues at the habitat level, and this could provide a beneficial emphasis on the holistic nature of ecosystems, with the “habitat” scale representing an important, but sometimes rather neglected and undervalued, “middle ground” for conservation.

Considering the above it is therefore necessary to see where ecosystem modelling fits within the decision-making process. Development of modelling tools will need to recognise the quality and quantity of input data that will be generated, and also the management support tools that will use the output data from the modelling process.

Figure 5.1 demonstrates the many interacting factors that have to be considered in catchment and coastal zone management. The figure is taken from the management approaches suggested by the EC for Water Framework Directive implementation (Schultz, 2001).

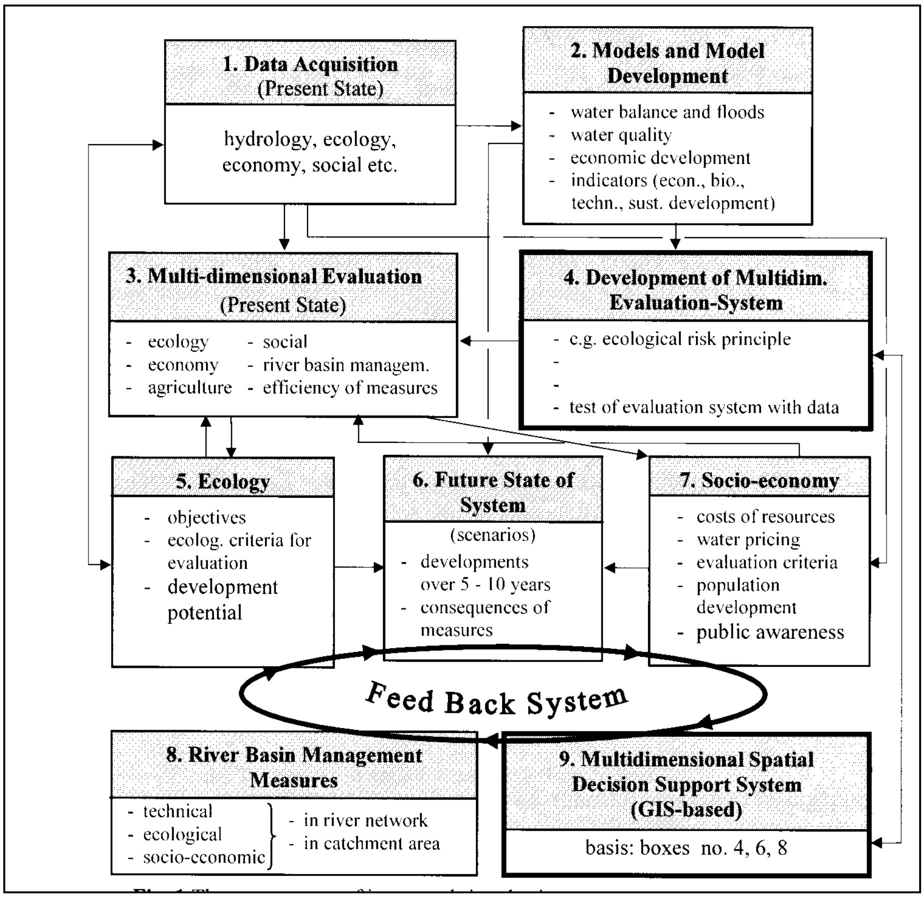


Figure 5.1 **Inter-related Factors That Require Consideration in Broad-Scale Planning (taken from Schultz, 2001)**

Interaction between many but not all of these disciplines is required for the consideration of ecosystem impacts. The key components for the BSEIM process are acquisition of appropriate data, provision of suitable ecosystem modelling tools and the application through a robust decision-support framework.

The following section describes each of these elements and the gaps in the present knowledge base. A synthesis of the various components is given in Figure 5.2, which demonstrates the inter-relationships and complexity of the data management and modelling processes that are likely to be required at a strategic level.

Compartmentalisation of the inputs and outputs helps to disaggregate the information requirements and the modelling tools that will need to be developed. At the largest scale BSEIM tools fit within a matrix, requiring input data from a range of sources and producing outputs that are suitable for incorporation into management decision-support tools.

A future BSEIM R&D programme is then recommended to meet the demands of the user community and provide an appropriate and robust set of tools for broad-scale ecosystem impact assessment. Seven BSEIM R&D projects are outlined. The R&D programme is summarised in Table 5.1 at the end of Section 5.

5.5.2 Input Data Requirements (Boxes 1 to 3)

Prediction of ecosystem interactions and changes requires a number of different types of input data and information. As demonstrated in Figure 5.2, the key data for BSEIM will be:

- Hydrology, hydrodynamic and geomorphological modelling outputs (Box 1)
- Catchment and coastal zone-based ecosystem baseline description (Box 2)
- Processes contributing to dynamic evolution of aquatic and floodplain ecosystems (Box 3)

The following subsections explore the data inputs required from each component and recommends R&D to fill the gaps identified.

Hydrological, Hydrodynamic and Geomorphological Modelling and Data Input

[see also Box 1 (Figure 5.2) and BSEIM R&D Topic 2 (Table 5.1)]

Aquatic and wetland ecosystem impact models rely on a range of hydro-geomorphological input data that determine the potential changes to:

- Morphology of habitats (bathymetry, bank and coastline shape, topography)
- Water flow, velocity, level and wetted area
- Bed, bank and channel stability and substrate availability.

These factors create the availability of niches, determine habitat availability and many of the prevailing environmental conditions that drive wetland and aquatic ecosystem function (of relevance to flood and coastal protection). Other factors will also be important, including land management practices and water quality, although these are not considered explicitly at this time. Suitable modules within a modelling framework will need to be developed, as these issues can have a similar if not greater impact on ecosystem integrity than does flood management.

Debate continues into the resolution of data required at a strategic level to assess ecosystem impacts. At present the CFMP and CHaMP planning systems develop relatively high level, low resolution data for the above parameters. However, the ecosystems that have to be modelled are driven by local scale factors. As an example, the Habitats Directive cSAC (candidate SACs awaiting ratification) conservation objectives often require very specific knowledge of the habitat and driving functions, that will require a relatively high level of modelling resolution. This is demonstrated by the (draft) conservation objectives for salmon:

- Flow regime should be characteristic of river (eg for migratory passage) in Ml/d or m3/s; suspended solids of <10 mg/l (annual mean); maximum silt content <10% in top 30% in spawning substrates; maintenance of juvenile habitat (required depth in centimetres) etc.

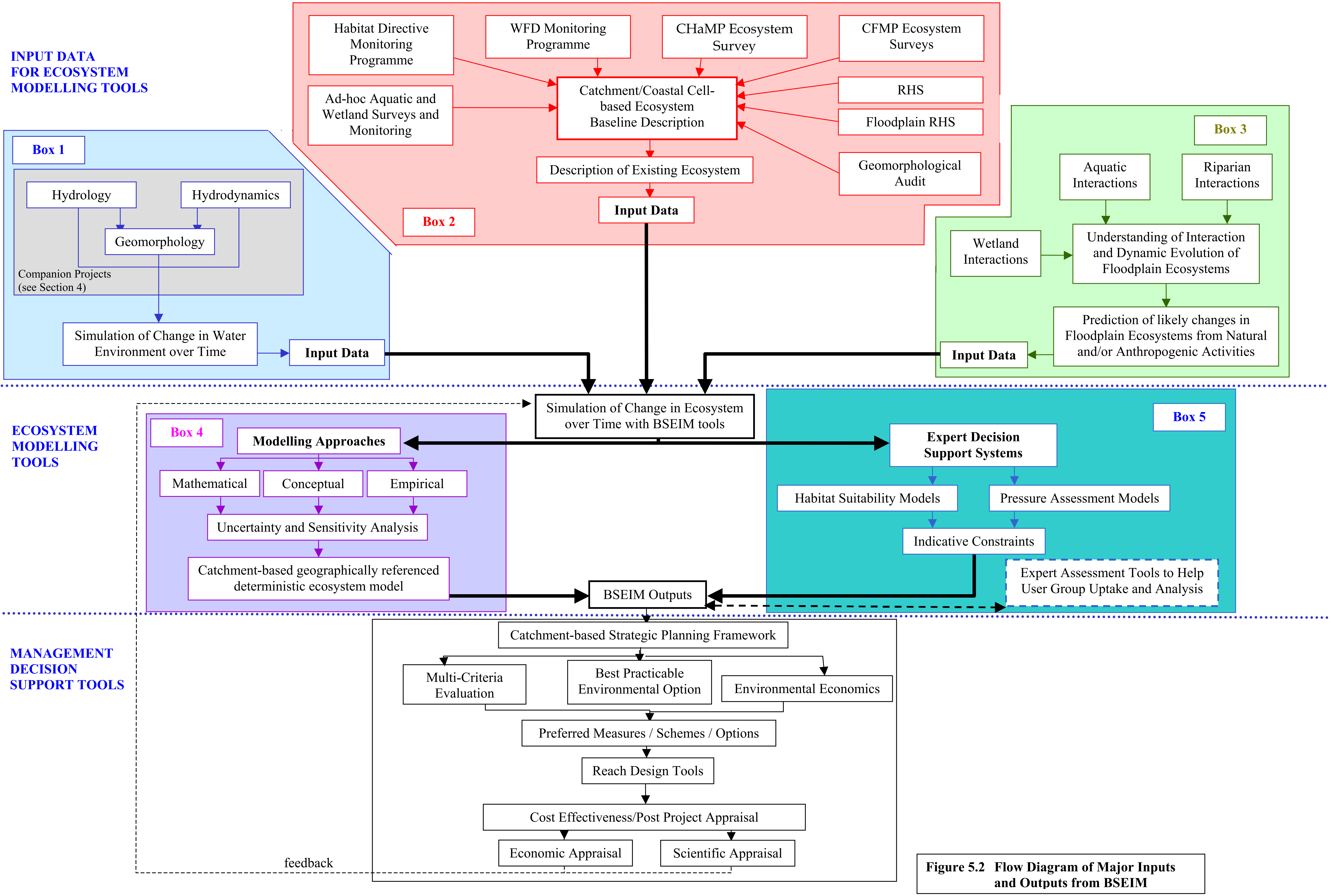


Figure 5.2 Flow Diagram of Major Inputs and Outputs from BSEIM

CFMP and CHaMP output will not deliver data at this resolution using the present guidance. It is likely that in the future, modelling of aquatic systems of notable conservation status will require information of a resolution that can be assessed against these and similar developing criteria. Recent experience with the conservation objectives has, however, taken a more pragmatic view in the absence of tools to simulate the ecosystem to the detail required. Planning for the future, and recognising the CFMPs and CHaMPs have to determine impacts on Natura 2000 site status, it is recommended that models of sufficient resolution are developed to allow such impact assessments. The R&D programme should recognise the potential differences in spatial and temporal scales of data output and the consequent BSEIM input requirements.

A study should seek to determine the most suitable spatial and temporal resolution of hydrological, hydrodynamic and geomorphological outputs that are adequate for use as inputs to the BSEIM modelling tools. It is likely that there may be different resolutions for different purposes. For example, in rivers it may be sufficient to have monthly trends, or for detailed assessments mean daily or hourly flows etc. In coastal and estuarine systems the resolution can range from multi-year simulation to tidal cycles. This work should form part of the BSEIM model development programme.

A number of research areas are suggested that merit additional study, including:

- Illustrative evaluation of the costs and benefits in terms of implementation requirements and prediction uncertainty of physically-based, simplified, parsimonious, but physically realistic models.
- Optimal raster resolution for different process representation in component sub-models of a Broad Scale Ecosystem Impact Model framework.
- Sediment routing procedures to be used in conjunction with distributed hydrological models based on distribution-function methods rather than explicit routing.
- Modelling of channel pattern and floodplain dynamics based on integrated vector and raster methods (without *a priori* definition of pattern types).
- Agent-based models of ecosystem succession processes in dynamic geomorphological environments (eg, floodplains, estuaries, salt marshes and coastal dunes).

Short-term output from this research will be a better definition of the hydro-geomorphological input data for qualitative or semi-quantitative ecosystem impact assessment. In the longer-term, it is likely that hydro-geomorphological outputs will be geographically referenced, probably within a GIS framework, providing spatially and temporally discrete data for input into integrated ecosystem modelling approaches.

Catchment/Coastal cell-based Ecosystem Baseline Description

[see also Box 2 (Figure 5.2) and BSEIM R&D Topic 3 (Table 5.1)]

In order to determine the dynamic changes to ecosystems over time it is necessary to know, where possible, the evolutionary processes leading to the existing state. In most cases this will not be possible, and a pragmatic approach is to determine the existing ecosystem baseline as a starting point.

There are a number of methodologies for describing aquatic and wetland ecosystems, whether from a holistic viewpoint (eg. National Vegetation Classification in Rodwell, 1992) or for individual communities (eg. macroinvertebrates) and/or species (eg. White clawed crayfish).

At present the ecosystem components that are included in the baseline description and the spatial resolution of the datasets tend to reflect the data that are available rather than the requirements of the modelling tools. Assessments tend therefore to be an ad hoc collection of ecological data rather than the holistic description that is required. Flood management strategies have tended to concentrate only on areas of recognised ecological importance as defined by international or national nature conservation designation. There is a strong case in BSEIM for a wider assessment of ecosystem integrity, as the dynamic evolution of catchment ecology is inter-dependent on both upstream and downstream connectivity (eg salmon migration). A holistic broad-scale ecosystem categorisation for in-river/aquatic, riparian/bankside and associated wetland communities should be considered on the basis of existing classifications, but co-ordinated to provide a more integrated approach.

For coastal habitats and communities the research and monitoring strategies are perhaps more developed, mainly through the work by JNCC (eg Hiscock *et al*, 1992) to describe coastal ecosystems and studies to develop remote habitat mapping. Work under the UK Marine SACs project will be of particular relevance, including the marine monitoring handbook (Davies *et al*, 2001). However, there remains a need to develop indicator habitats, communities and species and recommendations for the required level of data collection necessary to adequately describe the coastal communities. Defra has sponsored a number of workshops and reports on Ecological Quality Objectives (eg CES, 2001) and for the implementation of the Water Framework Directive. These studies have sought to identify indicators of habitat, community, population and species change, although not specifically for flood management purposes. Methodologies are also emerging using remote sensing techniques (eg satellite, sonar) that could usefully be employed for broad-scale ecosystem description.

Research is needed to recommend a consistent level of description from the datasets and the most appropriate collection and collation methodologies, to ensure that data are in the right format for ecosystem description and model use. The first step will be to define the range of habitats, communities and species of importance and from there select a range of indicators of stability and change (important to know which habitats and biota are most sensitive to changes in river/coastal water function). This is likely to be influenced by the catchment (eg. sandstone vs chalk) or coastal cell type (eg. shingle ridge vs saltmarsh) and will require a degree of rationalisation. The definition of characteristic catchments that function in a similar way would be a good first approximation (and, for example in the derivation of typologies using GIS, may mirror the work for the Water Framework Directive).

Having established the types of habitats, communities and species of interest it will be necessary to collect and collate the data in a consistent format. Work to this effect is being developed for riverine systems through the RHS and RHS Floodplain projects, although ecological considerations are less well developed. An additional RHS ecological module could usefully be developed. For the coastal zone a defined methodology is required, building on previous work from JNCC, Environment Agency and others.

In the short-term, use will have to be made of currently available data. In the longer term, the use of remote sensing is already being explored which could usefully be coordinated with ground truth observation, perhaps utilising an RHS-type module for ecosystem description (emphasising ecological features). Collation of data should ideally be through a GIS database.

The short-term output from this research will be guidance on where to obtain ecosystem data, in what format they are required, whether they are suitable for use and of the relevant quality (Analytical Quality Control/Quality Assurance), the preferred spatial and temporal resolution, and if necessary the methods to derive further data from field studies.

In the longer term a consistent format for data collection and collation will be developed within a GIS framework. The data will be derived to provide adequate spatial and temporal resolution, potentially using remote sensing techniques. Output format will be compatible with the input requirements of the BSEIM modelling tools.

Processes Contributing to the Dynamic Evolution of Floodplain Ecosystems

[see also Box 3 (Figure 5.2) and BSEIM R&D Topic 3 (Table 5.1)]

Broad-scale ecosystem assessment by definition needs to consider the interaction and dynamic relationships between habitats, communities, species and their individual and collective driving functions. Our understanding of the ecosystem web is far from complete and the vast number of processes that govern the dynamic evolution of habitats will not be fully established in the near future. Modelling of complex systems in such detail is therefore not practical at this time. However, many studies have sought to simplify the various interactions and have successfully integrated the environmental and ecological drivers in order to simulate habitat, community and/or single species dynamics. To predict the effects of flood management on riverine, estuarine and coastal ecosystems it is first necessary to understand the evolution and driving processes of the key indicator habitats, communities and/or species. It is likely that, for the monitoring, modelling and management of these, surrogate indicators can be determined and used. Again, this is the direction which may be taken by the implementation of the EU Water Framework Directive.

Work on developing this understanding is underway. An English Nature led project on Life in UK Rivers is currently producing a handbook on the requirements of river habitats and the 13 species listed in Annex II of the Habitats Directive (eg Salmon, Lamprey spp., Freshwater pearl mussel etc.). Similarly, for marine ecosystems the UK Marine SACs Project has investigated a number of communities (eg intertidal sand and mudflats and subtidal sandbanks, intertidal reefs, Maerl etc.) and indicated the degree of change and sensitivity of each to a given set of stresses, including change due to coastal squeeze, managed realignment and bathymetric change. A consolidation of the datasets is recommended, with further work to elucidate ecosystem interactions where gaps have been identified for these habitats, communities and/or species.

Of equal importance, a broader view is required of the more general riverine and coastal ecosystems to determine their needs. The work to date has tended to rightly focus on the most sensitive of UK ecosystems and species, but there is a compelling need to understand better the general function of the ecosystem, including those sensitive aspects. A framework for ecosystem assessment is needed that identifies, at the broad-scale, the most significant ecosystems for flood management. These will include components from in-river, riparian and associated wetlands. Having identified the first tranche of significant habitats, communities and/or species the study should develop an understanding of the necessary conditions to maintain their favourable status (hydrological, hydrodynamic, geomorphological and/or biological). Whereas this course has been taken for the implementation of the EU Habitats Directive, for a limited number of habitats and species, there is now the need for this to be carried out on the broader scale. This work will form the basic components of subsequent model development.

Clearly, it will not be possible to investigate every habitat and community. A pragmatic list based on user needs from the most pressing flood management strategy areas will need to be developed. The view can be taken that if the management protects the physical integrity of an area then the biota will be maintained, on condition that there is no excessive harvesting of that biota or any key elements of it. In the short term it will be necessary to collate all of the available data on the water requirements of aquatic and wetland species, updating the previous work by English Nature in this area (English Nature, 1997) and collating the findings of recent studies (eg Tollesbury etc.). In the longer term it is likely that a limited number of field trials will be required to establish the flow and sedimentary regimes necessary to support the indicator ecosystems and the implications of changes to ecosystem integrity.

The short-term output of this project will be a better understanding of the interaction of ecosystems with their supporting river and coastal processes. Through improved understanding of these dynamic interactions it will be possible to model the magnitude and significance of any natural or anthropogenic changes on ecosystem function.

Longer-term outputs will depend on the findings of earlier studies and the improving definition of process and parameter requirements to underpin the ecosystem models.

5.5.3 Ecosystem Modelling Tools

[see also Box 4 (Figure 5.2) and BSEIM R&D Topics 1 and 3 (Table 5.1)]

Detailed consultation has established that ecosystem modelling tools are required by the user community to better determine the implications of proposed flood management strategies, from which more sustainable policies can be developed. Tools should be developed that are adaptive to both user needs and to the specific requirements (level of complexity) of the ecosystems being studied.

Many different approaches are being advocated at present, ranging from purely qualitative to (quasi) fully quantitative. It is generally agreed that there is no single approach that can be implemented, and more fundamentally that the science underpinning the ecosystem approach is relatively under-developed. Recommendations from the expert consultation have concluded that a suite of modelling tools should be developed to cover the range of circumstances encountered. In general terms these can be sub-divided into:

- Quantitative modelling approaches
- Decision-support and expert systems

In the short-term, given the lack of detailed guidance, the consultation has flagged the need for guidance on BSEIM and ecosystem assessment. This is likely to take the form of a decision-support system, packaged as a BSEIM toolbox (Phase 1), until such time as the modelling approaches are developed sufficiently. Data obtained now and in the near future may be sufficient for descriptive and correlative (empirical) approaches prior to more theoretical models being developed in the later stages. Such initial approaches will also increase the knowledge and understanding of the relevant processes.

The types of modelling approaches that are available at present and which could be developed are discussed in Section 4. There are a number of promising tools, although none are at present in a form suitable for wide-scale application. Riverine ecosystem models are generally more appropriate to the reach-specific sub-catchment scale or tend to be very data intensive. Coastal and estuarine ecosystem models tend to be specific to a limited number of habitat types, although there are a number of empirically based models that could usefully be developed further for the simulation of, for example, saltmarsh generation and macroinvertebrate/bird interactions. Again, it is emphasised that where a good predictive understanding and capability is obtained for the physical driving forces in each ecosystem then the biological interpretation, even at a semi-quantitative level, can be superimposed. For example, if physical models are sufficient to indicate the changes to tidal bathymetry and sediments as the result of coastal defences then the resultant changes to the benthic invertebrates and their bird and fish predators can be estimated.

It is therefore recommended that a suite of models is developed, based where practicable on existing hydrodynamic and/or geomorphological modelling platforms, that can simulated at an appropriate resolution the changes to ecosystems as a result of changes in flood management strategy. It is suggested that several avenues should be explored, with the eventual model synthesising the most suitable developments.

A potential problem with tool development is the issue of R&D programme phasing. Over the next two to five years there is a potential bottleneck as the BSEIM studies wait for output from the companion hydrology and geomorphology R&D. However, the BSEIM tools can usefully overcome this by proactive determination of the input data requirements (e.g. flows, velocities and levels at appropriate timesteps) generated as output data from the hydrological/geomorphological models.

General Approach

In general terms the research should seek to develop initial qualitative network models for a pilot catchment and a coastal zone that describes the key forcing functions. This work will determine how the drivers are best represented in a simple model, and through which network connections they exert their influence.

In the medium term, over the 2 to 5 year horizon, the models should be refined and further quantification added. Sensitivity analysis should identify the strong and weak areas of model connectivity and focus development attention to those areas of key concern. A modular approach would be most suitable, allowing integration and building of the models and addition of new processes where required. This may facilitate incorporation of more diffuse interactions (eg. wading bird dynamics) to the more permanent core habitat network.

Over the longer 10 year horizon model refinement should be updated in a step-wise progression. The strengths and weaknesses of the modelling tools should be continually re-evaluated and where possible new data collected to fill knowledge gaps (particularly driving processes and dynamic ecosystem responses and interactions). Data collection may take a long time, given that simulations are supposed to demonstrate both broad-scale and long term variation. Recent Defra initiatives to harmonise and streamline monitoring, especially for the marine environment, may indicate the appropriate data.

In this way the modelling tools can be functional from an early stage, although with reduced confidence in those preliminary outcomes, progressing through to a fully integrated platform capable of ecosystem simulation with reasonable levels of attached confidence.

Quantitative Modelling Approaches - River Catchments

A hydrodynamic modelling platform will be required that can simulate, at an appropriate and therefore variable level of resolution, the changes in flows, velocities and levels in the river (and floodplain) system. Changes in river channel and floodplain geomorphology will also be required, although it is likely that this will have to follow and be incorporated at a later stage.

Based on ecosystem interaction data developed in the companion studies (see Section 5.5.2) changes in river characteristics can then be used as inputs to a modelling system that simulates the impact on in-river, riparian and associated wetland ecosystems. For the latter functionality it is likely that there will need to be a groundwater interaction module, which adds complexity but may be necessary to determine the driving water level requirements for wetland dynamics.

The recommended approach will be split over the 10 year period. The initial 2 year programme has two elements: i) specification of existing ecosystem prediction tools to support CFMP and ii) analyses and develop the modelling framework for the qualitative modelling suite. Key elements will include:

- Description of modelling tools appropriate for immediate application
- Development of adaptive management approach and supporting tool requirements
- Study to determine suitable spatial and temporal scales for range of BSEIM tools
- Identification of basic quantitative model structure and architecture, through identification of most suitable existing and emerging technologies (these may include proprietary or research-based models)
- Pilot studies for catchment and coastal models, using the recommendation from above.

The outputs from the Phase 1 will be a specific definition of the qualitative and quantitative modelling approaches to be developed in Phase 2, together with assimilated data for incorporation into the BSEIM Toolbox Phase 2.

The medium term programme will take the modelling framework and platforms specified in Phase 1 and populate the framework with modules for the significant ecosystem processes and interactions. During this phase it is likely that some of the hydro-geomorphological components will become available from companion projects. Modelling will have to recognise the information generated in Phase 1 on ecosystem function and interaction, and will have to incorporate the findings from the parallel studies in BSEIM 5.

Development of BSEIM tools over the longer term are difficult to specify at this time, given the relative lack of certainty in the hydro-geomorphological outputs and the speed with which ecosystem models/modules can be developed. It is likely that once initial ecosystem simulations begin to emerge there will be a number of questions and anomalies that will have to be addressed, such as poor model calibration/verification due to missing or poorly understood process interactions. In the longer term the models will have to be iterated to arrive at a reasonably robust predictive capacity. It is sensible to programme an ongoing research budget into the 5 to 10 year time horizon, as the complexity of the systems will always require a certain level of adaptation as user group needs evolve (and, as usually happens, greater resolution in the modelling outputs are deemed to be necessary).

A number of companies and academic institutions are developing ecosystem and ecological modules, using a variety of methodological approaches. The initial BSEIM quantitative approach should seek to embrace the most promising methodologies, adapting a hybrid approach using inputs from both “top down” empirical studies and “bottom up” process derived solutions. The most effective interaction of hydrodynamic, geomorphological and ecosystem modelling would be within a geographically referenced GIS platform. The pilot study should seek to determine the utility of such an approach, potentially within the general MDSF framework.

Model development should be on a pilot catchment. The catchment should ideally already have sufficient data to populate the ecosystem model. A number of modelling studies are underway in the UK at present that should allow such an approach, potentially including the NERC funded LOCAR studies and the UKWIR catchment water quality modelling approach.

In the short term, qualitative or semi-quantitative ecosystem impact assessment tools will be identified and specified to support the present need to predict future impacts from changes in freshwater processes. In the longer term a suite of spatially and temporally discrete ecosystem models should be developed that can integrate the major processes governing ecosystem function. It is likely that these will be GIS based and underpinned by hydro-geomorphological modelling data. These should be open-code models that can be updated and improved as knowledge is gained of ecosystem interactions.

Quantitative Modelling Approaches - Coastal and Estuarine Catchments

Hydrodynamic models are relatively well developed for coastal and estuarine systems. The geomorphological processes that are dictated by the hydrodynamic regime are also becoming better understood and there is a large R&D programme under the auspices of ERP2 to further develop the geomorphological component (see French *et al*, 2002). However, the consensus from the ERP2 programme has been a recognition that further fundamental and applied research is required to confidently predict estuarine geomorphological change over longer timescales.

Ecological modelling tools will have to be developed that can take the outputs from the hydrodynamic and geomorphological models currently under development from which to simulate changes to ecosystem function and integrity. It may be that an imperfect knowledge of the driving function has to be accepted until such time as the quantitative models become available. Despite this, even the qualitative or semi-quantitative prediction of ecological changes will be worthwhile.

A similar approach to that advocated for rivers is suggested for the coastal modelling tools. In terms of ecosystem function and dynamics, some of the fundamental science on the ecological inter-relationships is being established for the Defra and Environment Agency sponsored demonstration sites at Tollesbury and Freiston. Further work will be required to establish interactions for other indicator ecosystems in order to develop suitable predictive modelling tools. This work will follow the identification of the indicator habitats, communities and/or species (for coastal flood management). Models for these ecosystems will then be required, probably using the same framework and modular approach.

In the short term, qualitative or semi-quantitative ecosystem impact assessment tools will be identified and specified to support the present need to predict future impacts from changes in estuarine and coastal processes. In the longer term a suite of spatially and temporally discrete ecosystem models should be developed that can integrate the major processes governing ecosystem function. It is likely that these will be GIS based and underpinned by hydro-geomorphological modelling data. These should be open-code models that can be updated and improved as knowledge is gained of ecosystem interactions.

Novel Techniques

There are a number of novel techniques, as described in Section 4.4, that may have relevance to BSEIM. Some initial work has been undertaken through the Environment Agency R&D programme on the use of artificial intelligence for support to decision-making. A review of the technologies is recommended in the short term Phase 1 programme to explore their utility for either ecosystem modelling or for use within the decision-support system of the BSEIM Toolbox.

Decision-support and Expert Systems

In parallel with the quantitative modelling, there is a requirement for straightforward decision-support tools, particularly in the short term. These should include guidance on implementation of BSEIM, and will incorporate sections on:

- Simulation of change in the water environment (advice on hydrology, hydrodynamics and geomorphology)
- Description of the existing and historic environment (data sources and limitations)
- Interactions and dynamic evolution of floodplains (existing data on habitat, community and species interactions)
- Current approaches to prediction of ecosystem impacts.

In the short term a study is recommended to collate the information and produce the guidance document in the form of the BSEIM toolbox. The study should then investigate the utility of producing a more comprehensive expert system, within which the quantitative modelling approaches can be incorporated once suitably developed. It is of note that DSS experience elsewhere, for example the WADBOS Decision Support System for the Wadden Sea, will provide valuable information and approaches for use in a UK context. The toolbox should be updated periodically as experience is gained and new techniques and advances are identified.

5.5.4 Management Decision Support Tools

[see also Box 5 (Figure 5.2) and BSEIM R&D Topic 1 (Table 5.1)]

Implementation and improvements to BSEIM over time must be undertaken within the overall policy-making context and outputs from BSEIM should be directly relevant to the decision making process (see Figure 5.2). It is important that the outputs from BSEIM are in a form that can be assimilated into option assessment processes, such as multi-criteria evaluation (MCE), best practicable environmental option (BPEO) and/or environmental economic appraisal. An important consideration in all of these processes is that there must be confidence in the predictive outputs. Problems are routinely reported by decision-makers that the information supplied is not suitable for strategy assessment. Issues such as a lack of perspective on scale, magnitude and significance of ecosystem change are often quoted. Improvements in information supply, confidence in the modelling outputs and updating of methodologies to meet evolving user group needs can be greatly assisted by a formalised feedback process, possibly within the cost effectiveness assessment. This post project appraisal would analyse the simulated outputs from the modelling, with the actual changes over the short and hopefully long term, from which the accuracy of the prediction and further development of the modelling can be derived.

The recommended approach is to establish the different outputs required for the decision-making processes, including for new and developing methodologies (MCE, BPEO etc.). BSEIM tools can then be formulated to produce the required data and in particular information in an appropriate format, including the development of tools to allow estimation of relative importance of impacts in terms of magnitude and significance. These may be analogous to the IEEM guidelines on ecological impact assessment (Regini, 2000).

Consideration of ecosystem impacts in the wider decision-making context is hindered significantly by the present inability to monetise the positive and negative impacts. Environmental economics is developing rapidly as a discipline and the BSEIM toolbox must be developed in parallel to produce information that can be readily assimilated into the monetisation process. Unless this can be done, the true impact of policy on ecosystem integrity will never be fully rationalised by policy-makers. A study is therefore recommended that seeks to establish the links between BSEIM and the monetisation of ecosystem impacts, building on the work of CSERGE and others in recent years. The work should inform the resolution of modelling outputs (spatial and temporal scales) and the types of impacts that will require monetisation. For example, these may include costing a change in floodplain diversity; provision/loss of a wetland, reduction/improvement to a species range (eg Lamprey) etc. Once ecosystem effects can be fully monetised they can be fully considered in the decision-making process, including by the Treasury and others with budgetary considerations.

The outcome from these studies will be a system that takes relevant scientific information and converts it into a form appropriate to decision-making.

5.5.5 Training, User Support and Exploitation of R&D

[see also BSEIM R&D Topic 1 (Table 5.1)]

Responses from consultees have strongly recommended the need to develop appropriate training and user support to ensure the appropriate application of BSEIM tools. The techniques to be employed are relatively new or subject to recent development and workshop participants commented on the lack of modelling skills within the user organisations even if the modelling tools had been developed. Although the BSEIM toolbox guidance will be produced relatively early within the R&D programme this will need to be updated over time. An ongoing series of training modules is suggested for practitioners and operational flood and coastal defence staff to establish a clear understanding of the data availability, BSEIM methodologies, decision-support outcomes and particularly the potential limitations of the approaches taken. This training could be integrated with training for other complimentary initiatives such as Water Framework and Habitats Directive projects.

In association, recommendations from the Penning-Rowsell report firmly support the wider dissemination of R&D outputs. Best practice in information outreach, including approaches pioneered by CIRIA, should be explored and a programme developed for better integration of research findings into operational practice.

5.6 Summary

The need for BSEIM tools to support flood management strategy planning is well documented. The case is also made for an adaptive management approach that places the emphasis on an adequate level of study where it is required. This in turn dictates that a suite of BSEIM tools will be required, ranging from decision-support for relatively simple qualitative assessments to more complex deterministic modelling of significant and problematic interactions.

The BSEIM R&D programme should seek to provide guidance to the user community, through development of hydro-geomorphological and ecosystem impact models and tools to support decision-making and outputs that are appropriate to the level of decision-making. The proposed BSEIM R&D programme is summarised in Table 5.1.

Key topics include:

Short Term – Phase 1: within 2 years

- Development of BSEIM guidance: BSEIM toolbox
- Specification of data input requirements
- Development of suitable ecosystem baseline descriptions
- Interaction and dynamic evolution of aquatic, riparian and wetland ecosystems
- Development of hydro-geomorphological and ecosystem modelling approaches
- Catchment based strategic planning framework
- Training, user support and exploitation programme

Medium Term – Phase 2: 2 to 5 years

- Updating of BSEIM guidance: BSEIM toolbox Phase 2
- Baseline description and interactions – field studies
- Ecosystem modelling approaches Phase 2

Long Term – Phase 3: 5 to 10 years

- Mid term review of progress
- Baseline description and interactions – long term trials
- Ecosystem modelling approaches Phase 3

Outline project specifications for the short term projects, BSEIM 1 to 3, are contained in Appendix 6.

The modelling tools developed will be subject to errors associated with sampling, assumptions used, error amplification within and between models, errors in the assumed basis for links between models, stochastic errors and so on. There is a risk that the outputs from some of the R&D will not be very effective in supporting decision-making. It is important to note this possibility at the outset and put in place measures to minimise the amplification of errors through the modelling process. It is recommended that such risks are controlled by establishing an expert steering group that has suitable expertise and accepted responsibility to assess the risks associated with individual projects. The risk assessment and analysis of each project should be a standing item on the proposed project steering group bi-annual meetings.

Successful ecological impact models will continue to make uncertain predictions. To assure the delivery of benefits, users will still need to undertake adaptive management that defines the correct complexity of modelling tools for a given task and allows continued improvement of the models that reduces future uncertainties. Given the current reluctance to undertake post-project appraisal, the future opportunity to promote adaptive management and on-going improvement should not be lost, and is highly recommended by this research.

Also of importance, it must be possible to convert the outputs from the BSEIM tools into a variety of formats that are familiar to the end users, which includes giving a perspective to the predicted changes (what constitutes major to minor environmental impact) and for policy-makers must include monetisation of the ecosystem impacts and benefits. Environmental economic R&D to support ecosystem impact modelling is not considered further within this report, although consolidation and building on the ecosystem costs and benefits databases already available is strongly recommended.

Table 5.1 Summary of R&D Project to Develop BSEIM Tools

Ref. No.	Proposed Project	Examples of Related Projects/Programmes
Short Term - within 2 years		
BSEIM 1 (see also Section 5.5)	**Development of Initial BSEIM Guidance: BSEIM Toolbox Phase 1** To include basic data and guidance for qualitative assessments: • Descriptors of baseline ecosystem (aquatic, riparian, wetland); indicator habitats, communities and species; sources of data; AQC procedures etc. • Suggested approaches to ecosystem impact assessment for catchments and coastal waters, • Key texts on bottom up and top down predictive approaches for indicator groups • Methodologies to specify constraints and opportunities • Aid to development of preferred policies and/or measures **Training, User Support and Exploitation of R&D** • Develop appropriate training and user support tools to ensure the appropriate application of BSEIM tools. An ongoing series of training modules should be designed for practitioners and operational flood and coastal defence staff to establish a clear understanding of the data availability, BSEIM methodologies, decision-support outcomes and particularly the potential limitations of the approaches taken. This training could be integrated with training for other complimentary initiatives such as Water Framework and Habitats Directive projects.	Defra/Agency R&D FCD (see Section 4.8.1) CFMP/CHaMP guidance Geomorphological Approach to Flood Risk Assessment Geomorphological Input to BSEIM (proposed) Refined Geomorphological and Floodplain Component for RHS BSM MDSF Tollesbury and Freiston Trial Sites CIRIA uptake ERP2 (see Section 4.8.2) Hybrid model enhancement Sediment-biota interactions
BSEIM 2 (see also Section 5.5.2)	**Hydrological, Hydrodynamic and Geomorphological Model Development** • Definition of data input requirements for BSEIM tools - Assessment of outputs from hydrological, hydrodynamic and geomorphological models and consideration of the spatial and temporal data requirements for ecosystem modelling. • Analysis of the fundamental and applied research in hydrology, hydrodynamics and geomorphology to ensure that outputs produces data at a suitable spatial and temporal resolution to be useful for ecosystem and ecological modelling. • Development of initial hydro-geomorphological modelling tools that provide data of a suitable spatial and temporal resolution on which to base ecosystem impact assessments. • Determination of methods and formats for storing and sharing data.	Spatial landscape simulation Saltmarsh management techniques Defra MLIS (see Section 4.8.3) Value of Marine Benthic Faunas (CEFAS, MLIS CWO 840) Rapid Assessment of Marine Biodiversity (RAMBLERS) (CEFAS, CDEP 84/5/295) Water Regime Requirements and Response to hydrological change of grassland plant communities (Defra BDO225) Improve Understanding of Interactions
BSEIM 3 (see also Section 5.5.2 to 4)	**Development of Ecosystem Impact Modelling Approach – Phase 1** **a) Development of Suitable Ecosystem Baseline Description** • Identification of indicator habitats, communities and species for catchments and coastal zones subject to flood management policy appraisals • Identification of the most suitable spatial and temporal resolution for habitat, community and species mapping at a catchment and coastal zone scale • Development of habitat mapping tools to provide suitable data, preferably using pre-existing and agreed methodologies. These should be compatible and integrated with other catchment mapping techniques and technology. This may include floodplain mapping using CASI and LIDAR for flood levels, ecology etc.. • In the absence of existing data of sufficient resolution, a pragmatic short term solution is required to CFMP and CHaMP assessments. Guidance on the collation and assessment of data should be provided as inputs to BSEIM toolbox phase 1 (see BSEIM 1).	Between Sediments and Habitats (F10/F13) Habitat dynamics of wild salmon (Defra SF 0229/0331) Environment Agency (see Section 4.8.4) RHS methodologies Development of PQOs PHABSIM developments Application of Artificial Intelligence to River Management (Environment Agency R&D) English Nature R&D (see Section 4.8.5) Life in UK Rivers UK Marine SAC Project

Ref. No.	Proposed Project	Examples of Related Projects/Programmes
BSEIM 3 (Contd.)	**b) Interaction and Dynamic Evolution of Aquatic, Riparian and Wetland Ecosystems** • Research into the lifestage dynamics of key indicators habitats, communities and species in relation to flood flows and inundation and/or from geomorphological change (if these are found to be forcing functions). Attention should initially focus on the key species identified in EC Directives and UK regulations, with emphasis moving to a more holistic analysis after the first tranche of work, recognising the inter-dependence of aquatic and wetland ecosystems. • Better understanding of relationship between fluvial flooding and ecosystem function. What effect do changes in habitat availability and rate/longevity of inundation have on aquatic and wetland ecosystems? Scoping for medium term R&D field trials of ecosystem effects. • Better understanding of relationship between coastal flooding and ecosystem function. What effect do changes in habitat availability and rate/longevity of inundation have on aquatic and wetland ecosystems? Scoping for medium term R&D field trials of ecosystem effects. **c) Development of Ecosystem Modelling Approaches** • Description of modelling tools appropriate for immediate application for broad-scale modelling of catchments and coastal zones – simple mathematical, empirical and/or conceptual tools (for input to BSEIM toolbox phase 1). • Study to determine most suitable spatial and temporal scales for predictive capabilities for range of quantitative BSEIM tools and specification of the most promising combinations (integrated with the output from BSEIM 2). • Development of adaptive management approach that has nested broad-scale to local reach assessment format, for incorporation into BSEIM toolbox in phase 2. • Identification of basic structure and architecture of quantitative modelling systems, including a generic framework with specific modules to encourage further development. • Pilot study to describe most appropriate modelling tools for simulation of identified catchment-based indicators of habitats, communities and/or species – using sample catchment. • Pilot study to describe most appropriate modelling tools for simulation of identified coastal zone indicators of habitats, communities and/or species – using sample coastal zone. • Collation of novel techniques such as bayesian belief, neural networks, fuzzy logic, artificial intelligence, and specification of advantages/disadvantages of each for BSEIM applications (for potential medium term R&D) • Specification of framework for user-friendly modelling tool interface for incorporation into BSEIM toolbox phase 2 • Specification of decision-support/expert system platform for incorporation into BSEIM toolbox phase 2. **This project as with the others identified in the Table must recognise and integrate with work to support the Habitats and Water Framework Directives. This should ensure minimal duplication of effort and encourage development of consistent and inter-related assessment tools.**	NERC (see Section 4.8.6) LOCAR & CHASM programmes Suitability Criteria for Areas of Restored Habitat (URGENT) Evaluation of the Mapping and Assessment of Urban and Suburban Areas (URGENT - F04b) Modelling River Corridors (NERC URGENT) Rehabilitation of Urban Rivers: Modelling the Ecological Risks of River Sediments (NERC URGENT) Identifying Species and Ecosystem Sensitivities (MBA within MarLIN) UKWIR (see Section 4.8.7) Climate change and water quality modelling EU R&D IRMA-SPONGE Floodplain protection and Enhancement of Biodiversity in Large Western European rivers Floodplain Biodiversity and Restoration (FLOBAR 1 and 2) Floodplain Biodiversity and Restoration (FLOBAR 1 and 2) Scottish Natural Heritage R&D Pearl Mussel, River Dee and Glencoe habitats, Otter in the Spey Delft Hydraulics Nature Development and Valuation Module.

Ref. No.	Proposed Project	Examples of Related Projects/Programmes
Medium Term – 2 to 5 years		
BSEIM 4	**Updating of BSEIM Guidance: BSEIM Toolbox Phase 2** Incorporation of new, modified and alternative approaches, methodologies and data derived from research findings to take account of the R&D in the intervening period. The toolbox should also be updated to assimilate user comments and concerns to ensure that it remains focused and of use to the target audiences. It is likely that an extension to the predictive approaches with a range of audited technical approaches should be incorporated.	**[Iterated from Phase 1 Findings]**
BSEIM 5	**Ecosystem Impact Model Development** **a) Development of Suitable Ecosystem Baseline Description and Interactions of Aquatic, Riparian and Wetland Ecosystems** Following on from the short term data collation exercise, the medium term assessment should seek to identify key indicator ecosystem interactions resulting from changes in flood management practices: • Focused field studies to determine relationship between ***fluvial flooding*** and ecosystem function for specified habitat and/or communities • Focused field studies to determine relationship between ***coastal flooding*** and ecosystem function for specified habitat and/or communities • Need to better understand transitional flood plain communities to establish changes in inundation rates (both level and frequency) and the habitat and community preferences. • Integration of baseline ecosystem data in GIS framework, preferably within the same system as the hydrological etc. data. **b) Development of Ecosystem Modelling** Within the 5 year timeframe the ecosystem modelling tools should be developed to simulate key ecosystem interactions at a reasonable level of resolution and sufficient confidence on which to base management decisions. Development of a simple qualitative and a more complex quantitative modelling suite should have been specified as a product of the Phase 1 pilot studies. The models should allow the adaptive management approach to simulation of ecosystem impacts requested by the user groups: • Development of a qualitative tool based on sparse data that can determine a rough approximation of the range of changes in ecosystem function and integrity • Development of the preferred approach from ***catchment pilot studies*** to integrate hydrodynamic and geomorphological outputs to a quantitative ecological modelling platform. • Development of the preferred approach from ***coastal zone pilot studies*** to integrate hydrodynamic and geomorphological outputs to a quantitative ecological modelling platform. • Incorporation of a geographically referenced land use component into the modelling framework. • Integration of the hydro-geomorphological models with the ecosystem impact modelling tools.	

Ref. No.	Proposed Project	Examples of Related Projects/Programmes
Long Term - Up to 10 years		
BSEIM 6	**Mid-Term Review of Progress** Given the timescales involved, a review of technical progress and user group requirements is recommended. The review should be undertaken on the same basis as the existing BSEIM scoping study and should have similar objectives. It is hoped that by this time (5 years) many of the more fundamental issues will have been resolved and that a suite of modelling tools should be available in a toolbox format. Iteration of the R&D programme should have taken place after the initial 2 year phase of R&D, leading to a more focused and informed 2 to 5 year R&D programme stemming from development of the most promising modelling approaches. The 5 year review should therefore audit the previous R&D in terms of the objectives and outcomes. If necessary new objectives should be developed incorporating any new rationales that may have emerged (eg. through the Water Framework Directive) and re-focus the R&D to address the specific policy drivers.	
BSEIM 7	**Ecosystem Impact Model Development – Phase 3** **a) Development of Suitable Ecosystem Baseline Description and Interactions of Aquatic, Riparian and Wetland Ecosystems** The complexity of natural ecosystems and the subtle relationships between habitats, communities and species dictates that many of the processes determining the dynamic equilibrium of ecosystems will not be sufficiently well described within the timescale of the present R&D programme. The Phase 1 ecosystem baseline and interaction data collation exercise will determine which ecosystems are studies in greater detail in the medium term. It is also proposed that some of the more sensitive or subtle ecosystem relationships are studied over the longer term. The specification of ecosystem monitoring and development of process descriptions will require further definition during Phases 1 and 2. Research budget should be earmarked for these longer term data gathering exercises. There may be some synergy with other long term monitoring programmes that can benefit this approach. Field trials to establish long term changes in ecosystem function resulting from natural and anthropogenic influences. **b) Development of Ecosystem Modelling Approaches** The long term develop of the BSEIM suite will have to be informed by the outputs from the hydro- and geomorphological developments. However, the BSEIM workshop participants were confidence that appropriate tools at suitable data input resolution could be developed in the medium terms. The focus of the long term programme should therefore be the integration of a catchment or coastal zone based quantitative modelling suite that incorporates all of the key process drivers for hydro/geomorphology and the major ecosystem interactions in a GIS framework. R&D is likely to focus on the iterative development of ecosystem processes and interactions.	

6 SCHEDULE AND BUDGET

A total of 7 broad projects are identified for future funding (see Figure 6.1). The two long term studies, BSEIM 5 and 7, are necessarily indicative at this time and will require iteration towards the end of the short term programme in 2004. The principal components that form the foundations of the BSEIM R&D programme will be produced in the initial Short Term programme between 2003 and the end of 2004. In this period there will be an initial emphasis on production of guidance for flood and coastal defence project managers who have the responsibility for undertaking the CFMP and SMP broad-scale ecosystem impact studies, resulting in the development of the initial BSEIM Toolbox.

The Short Term studies will also assess, test and then propose a suite of modelling tools that will be fully developed within the Medium Term (2 to 5 year) R&D programme. Integral to this programme will be a definition of the indicator ecosystems and driving ecosystem processes and interactions that will need to be incorporated into the modelling framework (these outputs will also feed into the production of the BSEIM Toolbox).

The budget allocated for the initial Short Term two year programme is £490,000.

A budget of £5,000 per annum is recommended for expert advisers to the R&D programme. A small panel of experts should be convened twice per year to assess progress with the R&D programme and to iterate the programme specification. This expert overseeing role is seen as vital to the successful completion of the programme. The steering group should contain experts in aquatic ecology, hydrogeomorphology and mathematical modelling, and be convened soon and certainly prior to the next phase of the R&D for the specific purpose of reviewing and refining the Terms of Reference for the future R&D programme.

The Medium Term studies will follow on from the Short Term programme and will necessarily iterate as outputs from Phase 1 are realised. The BSEIM Toolbox will need to be updated to incorporate all of the findings from Phase 1. However, the main focus of the Phase 2 studies will be the collection of ecosystem data (remote and/or field studies) and the development of the preferred quantitative ecosystem modelling framework. Budget allocation for the Medium Term (2 to 5 year) programme is £565,000 (at 2002 prices).

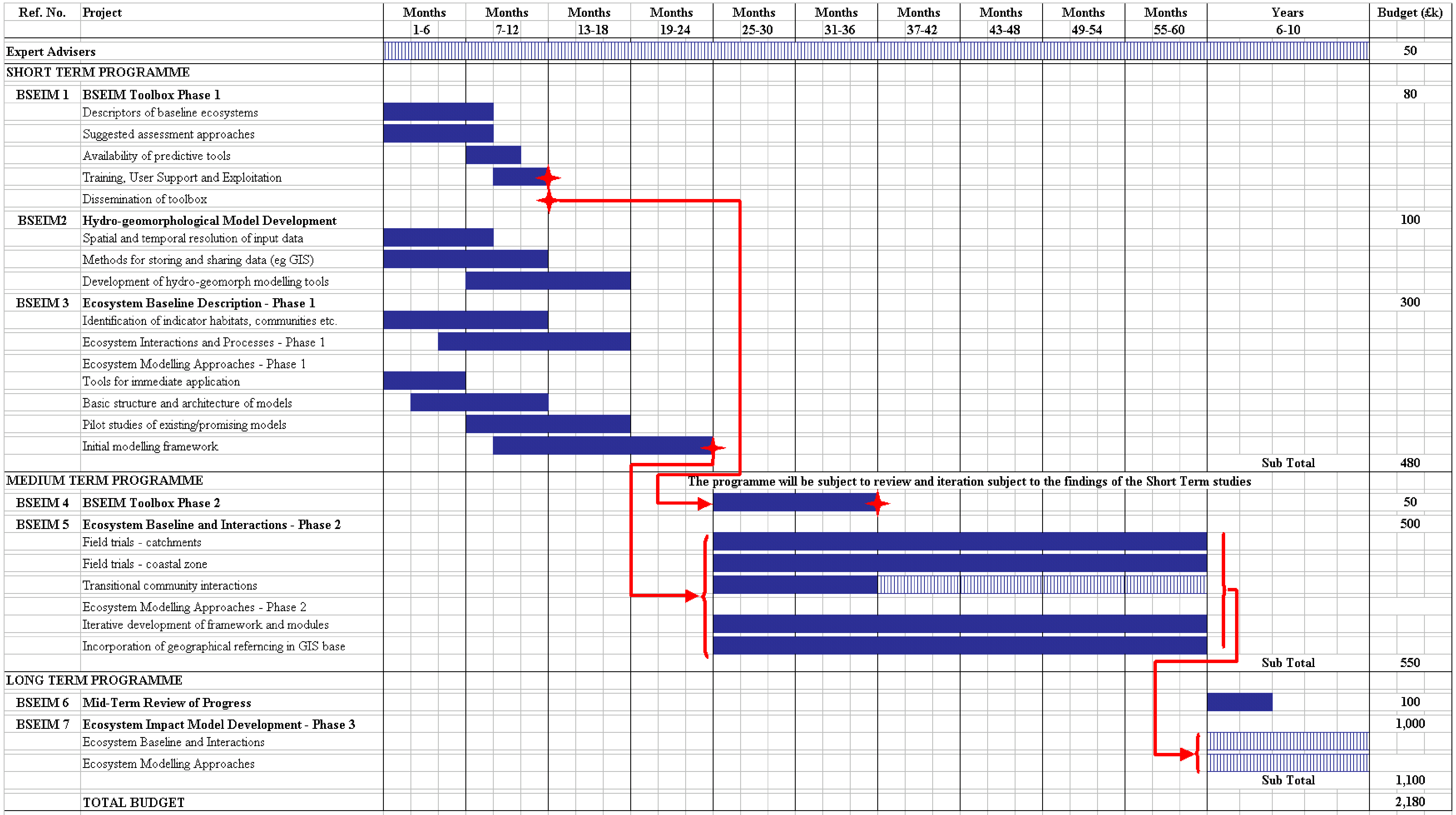
The Long Term (5 to 10 year) programme is necessarily indicative. However, a strong case is made to ring fence the budgets outlined, as there will need to be a significant level of model development and iteration into the longer term. For example, many of the processes and interactions will be investigated and identified within the Medium Term, the most important of which should be incorporated into the relevant framework modules. Clearly, there must be a limit to the resolution and confidence with which the BSEIM tools can and should be developed. However, the consensus would suggest that the optimum modelling platform will not be available until later in the 10 year programme (useable predictive models will be available in the nearer horizon but of a more limited performance). A budget of £1,150,000 has been suggested for the 5 to 10 year Long Term programme (at 2002 prices).

It is suggested that a re-definition of the Long Term programme is completed after the initial 2 year Short Term programme, as there are likely to be projects that will need to be funded for completion over the longer term horizon that will only be identified and specified after the basic research has been completed. A final note on the long term programme should be the recognition by practitioners that it is unlikely that it will be possible to deliver the final modelling tool that can predict all of the necessary hydrogeomorphological and ecological interactions at the required resolution and confidence. However, if progressed as recommended, the research programme will deliver very useful advances that will allow policy-makers and catchment/coastal zone managers to better understand the implications of their actions on a range of ecosystems. The R&D programme will act as a stimulus for further BSEIM tool development and should provide a firm foundation for delivery of the BSEIM vision over the following decades.

The budgets identified are acknowledged to be relatively modest compared to many of the other Defra/Environment Agency R&D programmes. It is recognised that budgets for ecosystem impact assessment are relatively restricted, and the budgets specified adopt a necessarily pragmatic delineation between research aspirations and operational requirements.

It should be noted, however, that additional funding streams such as co-funding through for example EC LIFE or Framework 6 or associated Defra, NERC, Environment Agency, English Nature, Scottish Natural Heritage, SNIFFER and UKWIR research interests should be vigorously pursued. This is particularly important for the hydro-geomorphological modelling component, as this element, although vital to the delivery of BSEIM, is not the main focus of the BSEIM R&D programme. Other funding streams will be required to fully develop the hydro-geomorphological capability over the medium to long term.

A significant avenue for co-funding could be the use that BSEIM tools will have in definition and determination of ecosystem effects that will need to be considered under other related regulation, including the Water Framework and Habitats Directives, and OSPAR/North Sea Conference commitments. A common feature of each is the emphasis on the "ecosystem approach" for long term environmental improvement.



Ref. No.	Project	Months 1-6	Months 7-12	Months 13-18	Months 19-24	Months 25-30	Months 31-36	Months 37-42	Months 43-48	Months 49-54	Months 55-60	Years 6-10	Budget (£k)
Expert Advisers		▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	50
SHORT TERM PROGRAMME													
BSEIM 1	**BSEIM Toolbox Phase 1**												80
	Descriptors of baseline ecosystems	■	■										
	Suggested assessment approaches	■	■										
	Availability of predictive tools		■										
	Training, User Support and Exploitation		■										
	Dissemination of toolbox												
BSEIM2	**Hydro-geomorphological Model Development**												100
	Spatial and temporal resolution of input data	■	■										
	Methods for storing and sharing data (eg GIS)	■	■										
	Development of hydro-geomorph modelling tools		■	■									
BSEIM 3	**Ecosystem Baseline Description - Phase 1**												300
	Identification of indicator habitats, communities etc.	■	■										
	Ecosystem Interactions and Processes - Phase 1	■	■	■									
	Ecosystem Modelling Approaches - Phase 1												
	Tools for immediate application	■											
	Basic structure and architecture of models	■	■										
	Pilot studies of existing/promising models		■	■									
	Initial modelling framework		■	■	■								
												Sub Total	480
MEDIUM TERM PROGRAMME						The programme will be subject to review and iteration subject to the findings of the Short Term studies							
BSEIM 4	**BSEIM Toolbox Phase 2**					■	■						50
BSEIM 5	**Ecosystem Baseline and Interactions - Phase 2**												500
	Field trials - catchments					■	■	■	■	■	■		
	Field trials - coastal zone					■	■	■	■	■	■		
	Transitional community interactions					■	■	▥	▥	▥	▥		
	Ecosystem Modelling Approaches - Phase 2												
	Iterative development of framework and modules					■	■	■	■	■	■		
	Incorporation of geographical referncing in GIS base					■	■	■	■	■	■		
												Sub Total	550
LONG TERM PROGRAMME													
BSEIM 6	**Mid-Term Review of Progress**											■	100
BSEIM 7	**Ecosystem Impact Model Development - Phase 3**												1,000
	Ecosystem Baseline and Interactions											▥	
	Ecosystem Modelling Approaches											▥	
												Sub Total	1,100
	TOTAL BUDGET												2,180

YEAR		1	2	3	4	5	6	7	8	9	10	Cost (£)
	Expert Advisers	5	5	5	5	5	5	5	5	5	5	50
BSEIM 1	BSEIM Toolbox Phase 1	80	-	-	-	-	-	-	-	-	-	80
BSEIM2	Hydro-geomorphological Model Development	50	50	-	-	-	-	-	-	-	-	100
BSEIM 3	Ecosystem Baseline Description - Phase 1	125	175	-	-	-	-	-	-	-	-	300
BSEIM 4	BSEIM Toolbox Phase 2	-	-	50	-	-	-	-	-	-	-	50
BSEIM 5	Ecosystem Baseline and Interactions - Phase 2	-	-	180	160	160	-	-	-	-	-	500
BSEIM 6	Mid-Term Review of Progress	-	-	-	-	-	50	50	-	-	-	100
BSEIM 7	Ecosystem Impact Model Development - Phase 3	-	-	-	-	-	200	200	200	200	200	1,000
	ANNUAL TOTAL BUDGET (£k)	260	230	235	165	165	255	255	205	205	205	2,180

Figure 6.1 Defra and Environment Agency FCD R&D Programme: BSEIM Tools

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Appendix 1
Terms of Reference

PART B - SPECIFICATION

Background

In June 1999 the joint Defra / Environment Agency Advisory Committee for Flood and Coastal Defence R&D recommended that the Defra/Agency R&D Programmes should be restructured and brought together.

Defra and the Agency accepted the overall proposals and developed new R&D programmes with the aim of achieving an integrated and user-led R&D Programme. Guiding principles included:

- All aspects of flood and coastal defence from developing strategic policy on flood risk management through to construction and management of hard defences must be covered;

- Research is justified from a user viewpoint, particularly through researcher/practitioner panels, to identify and address research within the context of current practice;

- Sustainability is included within technical, environmental, economic and social aspects;

- Benefits are delivered through enhanced performance or cost reductions; and

- Emphasis placed on dissemination and implementation of research outputs.

The background and development of the new Defra/EA combined Flood & Coastal Defence R&D programme is further explained in the 'Note on the New R&D Programme' attached as Appendix A.

Broad scale modelling

Broad Scale Modelling (BSM) forms one of six research themes established within the combined Flood & Coastal Defence R&D Programme. The rationale behind Broad Scale Modelling comes from some key phrases contained within the Advisory Committee Review, as follows:

- 'the huge investments made in the past may be under threat from climate change'

- 'there is a need to understand the frequency, extent and severity of coastal erosion and fluvial flooding likely in the future if we are to devise appropriate counteracting policies and schemes'

- 'there is a need to develop models that facilitate this understanding at a strategic scale of the catchment and coastal cell, and thus inform policy decision making'.

The theme therefore focuses on the belief that global modelling of 'whole systems' is now a feasible objective, and is needed to answer vital policy and risk questions. The policy objectives of BSM is to improve mathematical models in order to:

- Enable Defra/Agency to meet its policy aim of reducing risks to people and the developed and natural environment from flooding, through gaining an understanding of the large scale, medium to long term risks posed by such driving influences as climatic change and cumulative anthropogenic change;

- Discourage inappropriate development in areas at risk of flooding or coastal erosion; and

- Inform Defra/Agency as to the interaction between policies or strategies in such areas as planning, land use, agriculture, catchment management and flood defence, and flood risk.

The project outputs are likely to be of use to the Policy Development (PD) Theme and subsequent studies may be let to develop the recommendations set out in this Scoping Study.

Related issues within the Environment Agency and Defra

The joint Flood and Coastal Defence R&D Programme is structured into six research themes as indicated below:

<u>Defra Led</u>

- Fluvial, Estuarine and Coastal Processes (Theme Leader: John Pos, Mouchel);
- Policy Development (Theme Leader: Mike Child, WS Atkins); and
- Broad Scale Modelling (Theme Leader: Edward Evans, Halcrow).

<u>Environment Agency Led</u>

- Flood Forecasting and Warning (Theme Leader: Jim Haywood, EA);
- Risk Evaluation/Understanding of Uncertainty (Theme Leader: Ian Meadowcroft, EA); and
- Engineering (Theme Leader: Mervyn Bramley, EA).

In addition, there are a number of other initiatives being led or promoted by the Environment Agency, Defra and English Nature, which are strongly linked to the theme of Broad Scale Ecosystem Impact Modelling within flood/coastal defence or catchment management. These include:

- Catchment Flood Management Plans (CFMPs) Initiative – Defra/Agency led initiative to produce CFMPs for all 80 catchments in England and Wales. The guidelines are currently being trialled on five catchments (rivers, Irwell, Derwent, Severn, Parret and Medway);

- Decision Support Framework for CFMPs – Defra/Agency led initiative within the combined R&D programme to produce a common data structure and scenario models embedded within a Geographical Information System to support CFMP Initiative;

- Shoreline Management Plans (SMPs) – Defra led initiative providing guidance for the management of coastal erosion/protection. First round of SMPs have been produced, which are now being reviewed;

- Estuary Management Plans (EMPs) – English Nature led initiative to establish and manage pressures within estuaries First set of plans have been, or are currently being, produced;

- Coastal Habitat Management Plans (CHaMPs) – English Nature led initiative to establish management of coastal environments in accordance with the Habitat Regulations, 1994; and

- Physical Quality Objectives (PQOs) – Agency led initiative to classify existing quality and target quality objectives (including habitat and connectivity) of watercourses in England & Wales using the River Habitat Survey database.

Rationale for this project

The Advisory Committee for Flood and Coastal Defence R&D identified the need to establish predictive tools that take into account the multi-faceted interactions between different physical processes and their feedback effects, as well as the ecological, biological and socio-economics, to support flood management policy formulation and the decision-making process.

The committee identified a number of scientific research objectives for BSM, one of which established the need for Broad Scale Ecosystem Impact Modelling (BSEIM) as follows:

- Provide tools, methods and understanding to determine the broad scale regional and national impacts on ecological system integrity.

A BSEIM Topic Steering Group (TSG), including members from both the public and private sectors, was established to govern the future developments within this topic. It was acknowledged that no single coherent overview of this topic, specifically in relation to flood management, has been undertaken. It was therefore concluded that the first requirement was a Scoping Study, which would establish and document the present situation as well as establishing the way forward.

Objectives of scoping study

The overall objective of this scoping study is to:

- Provide an overview of the topic of Broad Scale Ecosystem Impact Modelling and define an appropriate and cost-effective research programme.

Specific objectives of the scoping study are to:

- Establish the environmental policy drivers and how these influence flood risk management (link to the PD Theme);

- Establish the user requirements, within the context of flood risk management, for Broad Scale Ecosystem Impact Modelling utilising case studies and other methods;

- Establish the existing Scientific, Engineering and Technology (SET) base with respect to BSEIM;

- Establish the current approaches used to estimate the impact of climate and anthropogenic change on ecosystems at a broad scale;

- Establish the links between BSEIM and other ongoing/future initiatives and research;

- Establish short-term, medium-term and long-term future research and development requirements; and

- Ensure that future BSEIM R&D is user-focused, is based upon consultation and consensus within the research/user community, and has agreement from the sponsors.

Tasks for consultant

The approach to the scoping study will be divided into four discrete phases (see Figure 1). The contractor will carry out the following tasks:

- Phase 1: Policy Drivers

Review the current and future environmental legislation, UK Government and EU targets and other mechanisms to identify the main environmental policy drivers. This phase will require careful communication with the Policy Development Theme Group and other relevant organisations to ensure complete coverage.

- Phase 2: Case Studies

Derive and evaluate the impact of the main policy drivers upon long term flood risk management planning by reviewing a series of case studies. Long term planning mechanisms can be conveniently split into two groups, as follows:

- ➢ Fluvial Systems: Draft national guidelines for Catchment Flood Management Plans (CFMPs) have been produced and are currently being tested in five pilot study catchments. Draft pilot studies are due to be submitted in September 2001. The consultant should use two or more of these catchments as case studies within this scoping study.
- ➢ Estuarine and Coastal Systems: The main vehicles for long term flood risk planning are Shoreline Management Plans (SMPs). However, Estuary Management Plans (EMPs), Coastal Habitat Management Plans (CHaMPs) and single scheme management plans under the Habitats Directive should also be considered. The consultant should establish appropriate case studies for the scoping study derived from these initiatives (final selection to be agreed with the TSG).

- Phase 3: Need for BSEIM

Establish the requirements for BSEIM, which must be user-focused, based primarily on the policy drivers and the case studies.

However, there will also be a need to undertake consultation with current/potential users to establish other requirements or uses for BSEIM outside the areas served by the case studies.

- Phase 4: R&D Solution

Identify the future BSEIM R&D requirements to help deliver long term flood risk management planning.

Firstly, this will involve establishing the existing Scientific, Engineering and Technology (SET) base by:

  - reviewing and evaluating current UK research knowledge in BSEIM;
  - assessing existing databases (e.g. RHS, Rivpacs) that could be utilised within existing or future BSEIM;
  - establishing past, current and planned future use of existing broad scale ecosystem impact models; and
  - reviewing/evaluating international research and application of broad scale ecosystem impact modelling.

It is expected that R&D requirements in the short term will be focused mainly on the existing CFMP programme based on existing research, scientific knowledge or methods. Short-term research will also need to take account of the requirement of the next round of SMPs as well as EMPs/CHaMPs. In addition, the potential needs of the Water Framework Directive River Basin Management Plans for BSEIM will need to be considered.

However, the short-term programme will also be complemented by a medium-term (3-5 year) programme of new research to provide tailored methods of assessing the catchment-wide ecological effects of changes to flood regime caused by climate change and other anthropogenic activity.

Lastly, a programme of more fundamental research, suitable for possible funding or co-funding by NERC, shall also be identified.

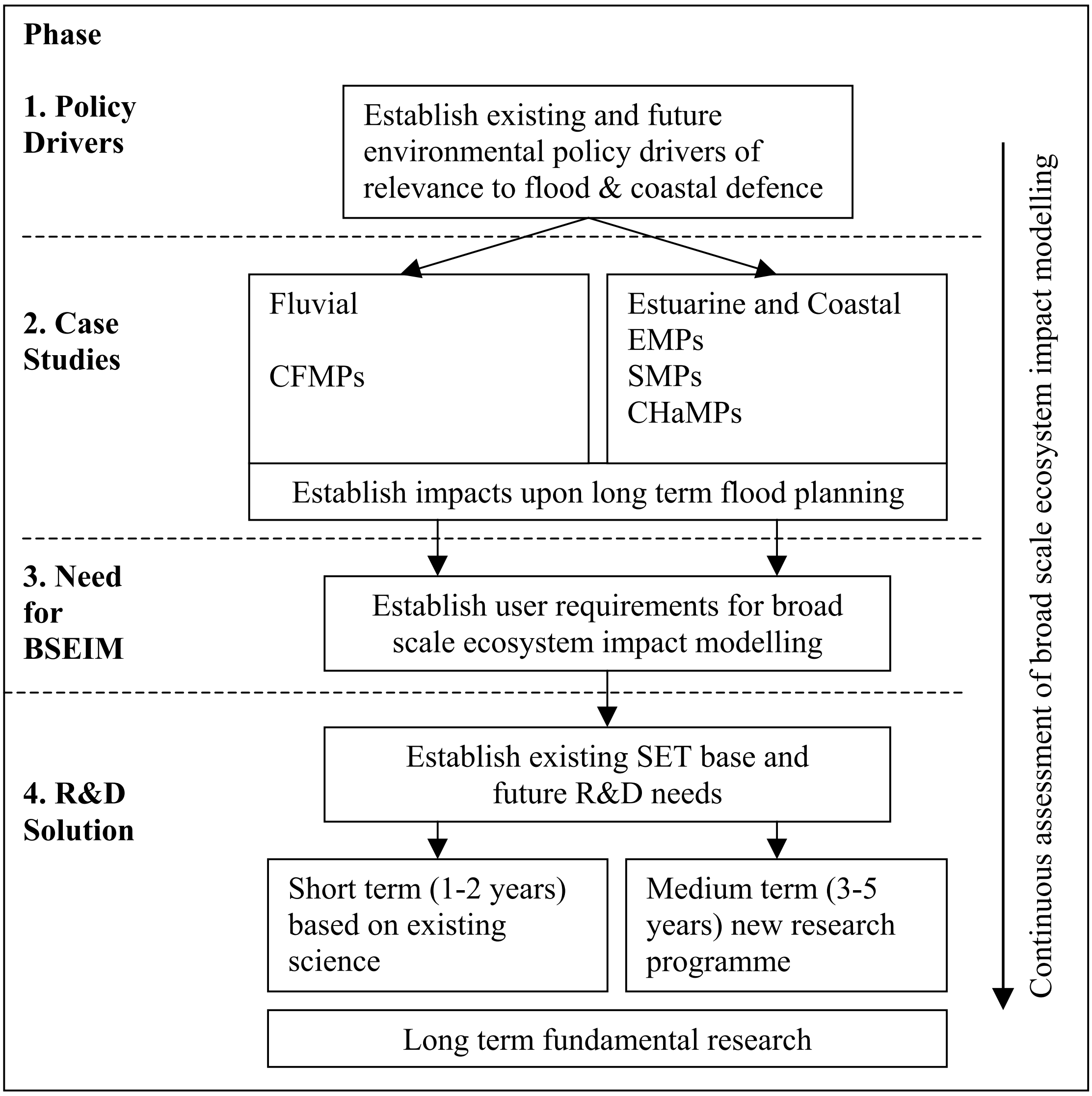
- General requirements

An underlying theme of the scoping study is the need within each phase to assess and comment upon:

  - whether and how broad scale ecosystem modelling is currently being used: and
  - how broad scale ecosystem modelling could and should be used to facilitate policy development and implementation in the future.

The topic of Broad Scale Ecosystem Impact Modelling is a cross-cutting topic encompassing the fluvial, estuarine and coastal environments. The scoping study will also largely be policy driven. Therefore the study must take account of the other five themes, with particular emphasis placed on the linkages with Fluvial, Estuarine and Coastal Processes, and Policy Development.

Figure 1 Illustration of the Scoping Study



Appendix 2
Workshop Structure and Participants

The framework for the workshop was as follows:

10.00 Introduction to the workshop and Objectives (Kieran Conlan)
10.05 Summary of the Policy Drivers (Kieran Conlan)
10.15 Use of BSEIM in CFMP/SMP/ChaMPs (Steve Dangerfield)
To include description of themes
10.30 How BSEIM is being progressed in flood and coastal protection at present (summary of case studies)? (Albert Nottage)
10.45 Breakout Groups to Confirm User Requirements
Questions to be answered included:
Do the presentations encompass all user requirements?
What do we need the tools for?
Who do we think will use them?
What level of complexity is desirable or required?
11.15 Plenary Reporting
11.30 Scientific Base (Rob Seymour)
12.0 Plenary on SET and morning generally
12.30 Lunch
1.30 SET Breakout Groups
Questions to be answered may include:
Are the policy questions answerable using ecosystem tools?
Are all of the possible tools identified?
Are the data available to support the tools?
What level of tool complexity is appropriate or will we require a range of approaches?
What level of confidence can we expect in any predictions?
Will monitoring and audit play a role in policy assessment and iteration?
Does risk analysis have a role in ecosystem impact assessment?
How should the tools be packaged for maximum uptake?
3.15 Plenary session on SET
3.30 Suggested R&D Programme
4.15 Prioritisation and costing of R&D
Close of Workshop

Participants in the BSEIM Workshop

Project Team	**Steering Group**
Kieran Conlan (Cascade Consulting) Bruce Munro (Cascade Consulting) Trevor Wade (Cascade Consulting) Duncan Painter (LUC) Mike Elliott (Hull Univ.) Rob Seymour (UCL) Albert Nottage (HR Wallingford)	Marc Naura (Environment Agency) Mark Diamond (Environment Agency) Steve Dangerfield (Halcrow) Edward Evans (Halcrow)
Accepted Invitation	
Paul Leonard (Defra) Ron Thomas (Environment Agency) Juliane Struve (Environment Agency) Glenn Maas (Environment Agency) Robert Willows (Environment Agency) Tim Sawyer (Environment Agency) Philip Winn (Environment Agency) Sue Reed (Environment Agency) Tom Coulthard (Aberystwyth Univ) David Gowing (Open Univ. Milton Keynes) Angela Gurnell (Birmingham Univ.) Colin Thorne (Nottingham Univ.) Mike Clark (Geodata, Southampton Univ.) Natalie Frost (ABP) Icarus Allen (Plymouth Marine Laboratory)	Beth Greenaway (Defra) John Pygott (Environment Agency) Helen Shardlow (Environment Agency) Martin Slater (Environment Agency) John Murray-Bligh (Environment Agency) Chris Pater (English Nature) Bill Walley (Staffs Univ.) Mark O'Connor (Staffs Univ.) Jon French (UCL) Steve Ormerod (Cardiff Univ.) Mark Macklin (Aberystwyth Univ.) Mike Acreman (CEH) Andrew Kenny (CEFAS) Peter Von Lany (Halcrow)

Workshop Programme

A number of initial papers presented the present policy position on BSEIM and flood planning more generally, followed by a detailed review of the present approach to ecosystem assessment in the Case Studies. The final paper described the existing and potential future directions of ecosystem modelling from a technical/theoretical perspective to give participants a view of the avenues that it may be possible to develop.

Four supporting papers were produced and circulated prior to the workshop to inform participants and provide a foundation for the subsequent workshop sessions:

Workshop Paper No. 1	Objectives and Drivers
Workshop Paper No. 2	BSEIM in Flood Planning
Workshop Paper No. 3	Case Study Summary
Workshop Paper No. 4	Ecological Modelling Approaches

The workshop participants were then divided into smaller groups to promote greater exchange of ideas, with two groups each for Coastal & estuarine and Freshwater ecosystems. Each group then considered the same set of questions.

The morning session was dedicated to development of ideas on user group requirements, to make sure that the BSEIM R&D programme is appropriately focused. The questions included:

1) What are the user requirements?
2) Who are the users?
3) What are the tools needed for?
4) Can policies be tested using the available tools?
5) What level of complexity is desired or required?
6) Do the users have the relevant skills to apply the tools?

The afternoon session was specifically targeted at a discussion of the scientific basis of BSEIM, the existing situation, the gaps and the possible avenues for future research. Eight questions were put to the participants:

1) Can the policy questions be answered using ecosystem tools?
2) Are all of the possible tools identified?
3) Are the data available to support the tools?
4) What level of tool complexity is appropriate or will we require a range of approaches?
5) What level of confidence can we expect in any predictions?
6) Will monitoring and audit play a role in policy assessment and iteration?
7) Does risk analysis have a role in ecosystem impact assessment?
8) How should the tools be packaged for maximum uptake?

The findings of each group session were recorded and fed back during the subsequent plenary sessions by the group chairmen. The findings of the group sessions, recommendations from the workshop and detailed discussions with key consultees form the basis of the thinking that underpins the future R&D programme.

Appendix 3

Workshop Summary of User Group Requirements (Table A) and Scientific Base (Table B)

Table A – USER REQUIREMENTS
What are the user requirements?
Stakeholders should include politicians and the wider public, not just experts, with outputs at a level suitable for each group.
All stakeholders should be able to understand the model output, and preferably something about the basis on which modelling tools are constructed
Impact assessment is usually too little too late, and usually based on opinion. More focus should be given to assessment from inception.
Exploratory tools to aid judgement well in advance of implementation are required
There is a need to steer away from the impact on species and look at impacts from a holistic ecosystem viewpoint
There is a definite need to address habitat replacement on an ecological basis in a strategic way. At present the replacement of habitat is addressed on a physical basis, in an ad-hoc fashion
There is a need for capability of assessing the impacts of schemes in combination with natural processes
Needs to be some means of prioritisation or ranking of the end user needs
There is a need to clarify the issue of scale. Most current work is local and site specific. A nested approach is needed to encompass different scales.
Identifying opportunities for habitat restoration should not be forgotten amidst the emphasis on impact assessment.
There is a need for models to allow users to take into account water/sediment quality issues and the effect on the ecology.
Models should capture the dynamic evolution of the river or coastal system.
Who are the users?
A wide range of users were identified including:
Practitioners – consultants, academics, strategic planners
Regulators - Environment Agency, Defra, English Nature
Other statutory consultees (Crown Estates etc.)
Operational staff – Environment Agency, local authorities
Wildlife Trusts and nature conservation bodies
Developers
Recreation and amenity groups
Fisheries interests
Local interest groups
Port Authorities
Local Authorities
Industry (eg marine extraction, power suppliers)
General public (but not last in the order of consultation)
What are the tools needed for?
Tools needed to predict the impact of management options and the variability/uncertainty in the environment
A need for model outputs to provide justification of (flood/coastal defence) schemes in terms of their impacts on habitats
The main use for models is to reduce uncertainty and help direct decisions

In terms of adaptive management, there is currently no modelling linkage available. BSEIM tools are needed to provide this linkage
Mathematical or statistical based models may be better than qualified opinions because variability and errors are consistent and can be controlled.
There is a need for a suite of ecological tools directed at specific objectives. (e.g. –). Tools are needed that are capable of demonstrating the impact of flood defence schemes on habitats, conservation status etc. Indicators of habitat etc. sensitivity are required to establish what are we trying to protect/enhance. Should aim for emphasis on habitats, get away from emphasis on species unless there is clear evidence that these are keystone.
There is a need for development of linkages between physical processes and biological responses
It must be recognized that BSEIM tools are the top tier of models/tools – these are then supported by more detailed strategic and scheme-based models/tools. BSEIM will not answer all of the questions and will need to be interpreted.
Tools must be focused at the ‘broad-scale’ – they are to assist in making catchment-wide decisions not, for example, where or how big a flood wall should be in a specific location.
Uncertainty will be very difficult to assess with any precision. At a broad scale probably the best that can be hoped for in the short term is an indication of which (qualitatively defined) scenarios are more or less likely. For example, scenario A occurs once in every 1000 computer runs of the model, whereas scenario B occurs once in every 10 runs.
More data are always useful, especially for short-term prediction, but are not always decisive for medium-to-long-term prediction. The latter can only really be done by scenario (“what if”) assessment.
Can policies be tested using the available tools?
No, the tools are not currently available.
It is believed that models exist to test flood defence measures at the local or site-specific scale only, and few can simulate whole habitat impacts.
The current approach is therefore to adopt over-precautionary approach
Hydrological/hydrodynamic change can be modelled at catchment/coastal cell resolution. No link to ecosystems is currently available.
Similarly, workshop participants believe that tools are available to model sediment movement (accretion and erosion) at a catchment scale over a long timescale. There are no links to habitats and species dynamics.
BSEIM tools need to be developed to support policy assessment. A first phase BSEIM toolbox could be developed within two years that contains guidance and simple modelling approaches to aid specific policy testing although a robust modelling suite will require longer development.
The BSEIM toolbox would have the advantage that it could be used to define wide-ranging policy-testing protocols and through adaptive management approaches be sufficiently versatile to cover all user group needs.
What level of complexity is desired or required?
Models are not only for specialists. Understandable outputs must be produced for local stakeholders, planning officers etc.
There is a need for exploration of innovative modelling methods
There remains a need for integration of existing models/ tools and development of an integrated BSEIM platforms

Issue of scale: i) Micro-scale models may be more reliable but they are data intensive ii) Macro-scale models are simpler to use but provide ‘rough’ outputs and issues are often site-specific. However, combined with a monitoring strategy, they can help manage uncertainty (adaptive management)
Level of complexity needs to be appropriate for the spatial and temporal conditions
Tools/models need to be able to capture the dynamic nature of the environment
Tools need to be simple, robust and cost-effective (given the known levels of resourcing, funding and computational power available to the users)
Model complexity is probably a less important issue than model transparency. That is, is a modelling tool easy to use, and is its output easy to understand for all stakeholders? What goes on inside the black box is less important, except in regard to the practical limitations of computer power required and availability of data.
Basically, the simpler the better, but there is a trade-off between simplicity and confidence. However, it should be borne in mind that stakeholders who are opposed to a particular policy will always find reasons to distrust any model output, however complex. This is a problem for politicians, not modellers.
Do the users have the relevant skills to apply the tools?
Existing potential users do not have the skills to understand/interpret the outputs. They need to be aware of the levels of uncertainty associated with the models. A training and recruitment strategy are needed as well as a friendly front end for the software.
In terms of physical modelling, most users do not have an understanding of the processes, they just use the outputs and treat the models as a ‘black box’
At present the linkage between physical processes and ecological effects is not fully understood
Many of the future operational users of the BSEIM toolbox do not have detailed modelling skills. There may need to be at least two levels of use, with technical users implementing the more complex modelling tasks with operators, policymakers and the public having a more qualitative role. A key role must be the interpretation of model outputs and ‘what-if scenarios’ that must be presented in a simple manner.
Training of users (e.g. Environment Agency) will provide an important element of research/model output uptake.
A training programme will be required. In particular, limitations of any modelling tools must be transparent and easily understood. Users must be helped to understand that their expert judgment is not made redundant by a modelling tool (any more than a doctors is by a stethoscope) and must not be alienated by the technology.

TABLE B – SCIENTIFIC BASE

Freshwater	**Marine/estuarine**
Can we answer the policy questions using ecosystem assessment tools?	
The policy issues are broadly about managing change (e.g. climate change, land-use change) sustainably, cost-efficiently and with wide stakeholder support. Within this, there is a requirement to protect and (where possible) enhance the environment.	Key policy questions include legal obligations to protect habitats and species; the need to safeguard people and property; the provision of sustainable flood and coastal defence; facilitating sustainable development
Many policy questions are answerable at the broad-scale	Policy questions can be answered using the ecosystem assessment tools but the degree of certainty is not known
"Policies", e.g. do nothing, maintain flood risk, reduce flood risk or increase flood risk, will be hard to model. Only "measures" (storage, improved conveyance, flood warning etc), which implement policies, can be tested and modelled.	In terms of the SMPs the levels of certainty are much clearer for physical processes than for ecosystem assessment
Data need to be collated and its quality assessed. Indices of pressures on habitats would be useful (based on RHSs).	There is a reasonable understanding of coastal processes in the short term timescale
To protect and (where possible) enhance the environment the threats need to be identified at the broad scale and then focused down to more specialised reach-scale modelling (e.g. with respect to SACs or SSSIs – though there is probably too much emphasis on the importance of these).	There is much greater uncertainty in longer term prediction, leading to a precautionary approach. Beyond a 10 to 15 year timescale the prediction of impacts is based on extrapolation of shorter term predictions, leading to much greater uncertainty
Using macro scale models general statistics can be produced on the following key indicators: Habitat diversity; Habitat quantity and quality; Habitat connectivity; Habitat rarity; Erosion/deposition patterns; Geomorph activity; Ecosystem resilience; Pollution etc…	There is a need for greater understanding of levels of uncertainty for biological/ecological variation
Tools exist to model hydrology and sediment movement (accretion and erosion) at a catchment scale over the long timeframe. No models exist to link these changes with ecology at the catchment scale	Currently the tools are available for hydrodynamic predictions but models/tools for assessment of ecosystem impact are not yet available
Are all of the possible tools identified?	
There are a number of modelling groups developing potentially useful models in a variety of formats. None would appear to be realistically implementable in a short timescale.	All major methodologies/approaches have been identified as well as all tools currently available
We know what the possible modelling approaches are. We know much less about their relative strengths and weaknesses in relation to answering specific questions. At present this can only be based on 'expert judgment' and trial and error	A suite of physical predictive tools are already available, the majority of which are 'closed code'
There is a belief that the problem and requirement for modelling (i.e. what do we need to know) needs to be clearly defined before the type of model (e.g. mathematical, Bayesian) can be established.	Current ecological models are only at the research level
Belief in certain quarters that suitable site-specific ecological models are available that can be transferred to catchment-scale (eg. PHABSIM) although some concerns about "ecosystem" relevance of species specific approach	ERP Phase 2 (EMPHASYS project) suggests a combination of modelling techniques. There is potential for further development of this approach to incorporate ecosystem effects
APEM and CEH are currently researching generic catchment-wide fish habitat assessment methods based on site-specific data that may be appropriate models for adoption for other ecosystem aspects	
Are the data available to support the tools?	
An large body of data are available, particularly of hydrology and geomorphology	Monitoring data are lacking to support ecological models
Fewer data are available on ecosystems and would need to be available on a national basis	There is a need for integration of existing biological, chemical and physical data
Habitat survey data are potentially very important, as are presence/absence data, although no consistent methodology is available for all aspects.	There is a need for better QA on data
Low resolution ('quick-and-dirty') classification data may be more suitable for broad-scale modelling than more focused quantitative and localised data of specific features, except at sites which have been identified as particularly vulnerable.	At present data acquisition is not necessarily 'fit for purpose'
In the first instance use of nationally extensive and validated data sets may be preferred option (e.g. invertebrates [RIVPACS], habitat [RHS] and plants [MTR])	Data are available for some systems but not for others, with inconsistent measurement and coverage
There are plenty of data available that can help us identify the sensitivity of species/communities. It may even be possible to identify indicator species/features.	Much more detailed data are needed for accurate predictions of ecological change

TABLE B – SCIENTIFIC BASE cont.

Freshwater	**Marine/estuarine**
Data acquisition tools are needed to help extract any relevant data. Ideally, a meta-database should be produced but it is costly	
Data quality is also another major issue	
What level of tool complexity is appropriate and what confidence can we expect in any predictions?	
The focus of the tools should be on the modelling of ecological indicators at the broad scale	Tool complexity should be ‘fit for purpose’, and will depend on the level and scale of application, and on the level of certainty needed in the prediction
The cost of running the model must be aligned with the resources available to implement CFMP	The level of uncertainty becomes much greater the more detailed the prediction
The model must fit in with existing resource constraints (e.g. staff availability, staff expertise, funding, short timescale for use, information availability, computational capabilities etc.)	Problems of uncertainties lie with linking physical to ecological processes
The model at the CFMP level is to identify option non-starters not to answer questions in the finest detail. Confidence levels can be quite large, standardisation/comparability of options/catchments is more important.	Modelling of morphological evolution in the long term is not currently possible – coupling this with ecosystem models will lead to multiplication of errors and therefore much greater uncertainty over the long term
Model transparency is as important as model complexity. The modelling tool should be easy to use, and is its output easy to understand for all stakeholders.	There is a need for understanding of limits of predictability to gain confidence in the results of modelling
The general view was that the simpler the tools the better they would be accepted and therefore used, with a trade-off between simplicity and confidence. However, it should be borne in mind that stakeholders who are opposed to a particular policy will always find reasons to distrust any model output, however complex. This is a problem for politicians, not modellers.	Members from workshop were in common agreement that a network type model was most appropriate for estuarine systems – aiming to determine the direction rather than quantification of change
There could be 2 scales of modelling:i) Macro-scale for catchment assessment; ii) Micro-scale for site assessment And 2 timescales for development: iii) First aid - qualitative modelling; iv) 3-5 years: quantitative modelling	
Will monitoring and audit play a role in policy assessment?	
Monitoring will form a very important part of the BSEIM process on two fronts; firstly, monitoring model development/prediction; and secondly, monitoring catchment response. These two elements are integral and iterative as one feeds into the other.	There is a need for monitoring to verify model predictions – comparing predictions with observed data will give the ability to note the uncertainty of the model and also allow future development
Preferred modelling approaches that look promising should be refined and monitored.	Monitoring is crucial in understanding the physical and biological basis of the model
It may be useful to develop parallel modelling technologies so as to monitor the relative robustness of outcomes. This would be cheaper than testing predictions against data – especially as the latter might take years to do effectively	Monitoring is needed to ensure compliance with policy driver(s)
Monitoring must be used to underpin management. Models will not be able to deal with the uncertainty in the system and monitoring will help to adjust to sudden changes in the environment.	Monitoring and audit should be a more integrated process to give closer links between monitoring and policy assessment
How should the tools be packaged for maximum uptake and will a range of approaches be required?	
Need for a model capable of generating and modelling long-term “what-if” scenarios	Modelling package should be suitable for the users i.e. Environment Agency, English Nature, developers etc.
Packaging is a very important aspect. The end-system should be a synthesis balancing policy needs and user skills, with training and QA included	Interpretation should be key to modelling package – the tool(s) would need to be designed to enable users to interpret the output of the model(s). Package is therefore likely to require user-friendly interface
A strong emphasis should be placed on training as part of the modelling package	There would have to be an integrated training programme to enable users to fully understand the package
Recommendations of a two-tier modelling approach i) Broad-scale ii) Detailed ecological response (although may be dealt with at a strategic/scheme level)	A hierarchical approach has been suggested: i) A qualitative network approach – to determine the direction of a response at a broad scale ii) More detailed modelling for specific areas/issues

TABLE B – SCIENTIFIC BASE cont.	
Freshwater	**Marine/estuarine**
The importance of quality control should be recognised	A longer term goal would be the development of a decision support system – linking of models and management options through a GIS.
A user-friendly front-end will be an important component of the package	Model code should be open – to enable model development in response to new or revised knowledge of ecosystems and responses.
Data extraction tools should be included as part of the package to enable data to be derived from various sources	There is an immediate need for appropriate tools and models that work, and guidance on application of best practice.
Research output needs to take into consideration CIRIA uptake study. Unless BSEIM is packaged, presented and delivered in a way that users can understand and use the research will be wasted.	Data collection and collation is inconsistent. There is an urgent need for a system that allows the users to access available data and top specify new data acquisition in a consistent format.
Three types of system may be needed: i) "Dashboard" indicators: using simple data such as RHS and a range of indices such as: habitat diversity; habitat quantity and quality; habitat connectivity; habitat rarity; erosion/deposition patterns; geomorphological activity; ecosystem resilience; pollution etc… are calculated and presented on an ecosystem management 'dashboard' as a series of coloured indicators (green, amber, red). Expert opinion would still be needed to set the thresholds for the various indicators. ii) Quantitative models to simulate catchment ecosystem response to changes in hydrodynamic/geomorphological character. iii) A decision-support system is needed to help managers narrow down the range of management options and direct them to the best sustainable management options. The system will be built using expert opinion and existing knowledge on catchment management. It will use the data provided by the dashboard indicators and/or models to help derive the best management policies.	

Appendix 4
Science Base Summary Matrix

Modelling System	**Tool Type**	**Country& Source**	**Area covered [coast/rivers]**	**Relevance to Ecosystem Modelling**
Algal Growth	Compartment model	US	Rivers	Algal dynamics
ASRAM	Empirical	Canada, Jorgensen	Rivers	Atlantic Salmon
Biogeochemical Nutrients Cycling in Large River Systems (BINOCULARS)	Mechanistic	EU, Cordis programme	Rivers	Nutrients and biota
BioRap	Conceptual	Australasian	Coast	
Biotide			Coast	Sediment transport
CAESAR	Mathematical /dynamic	UK, University of Wales, Aberystwyth	Rivers	Sediment transport and GIS
CemoS/water	Compartment	Germany	Rivers	Contamination and biota exposure
CL-CCE	Expert System	Netherlands, Delft Hydraulics	Rivers	Soils and water quality
Coastal Ecosystem Landscape Spatial Simulation (CELSS)		US	Coast	
Coastal Engineering Design and Analysis System (CEDAS)	Mathematical	US, Coastal and Hydraulics Laboratory (CHL), Vicksburg, Mississippi.	Coast	No ecology. Made up of 4 modules including Surface Water Modelling System (SMS).
Computer Aided Simulation Model For Instream Flow Regulation (CASIMIR)	Mathematical/dynamic	Germany, University of Stuttgart	Rivers	Fish, macrophytes and benthic species
Conservation Area Landscape Model (CALM)	Not specified	Maryland International Institute for Ecological Economics / South Florida Water Management District	Wetlands, canals	Spatially integrated ecosystem and landscape model
Coupled Ecological and Socio-Economic Model (CECOSECOM)	Mathematical/dynamic	France/UK	Rivers	Eutrophication and lower trophic groups
Delft3D-ECO	Mathematical/dynamic	Netherlands	Coast/rivers	3D hydrodynamic model with simple ecosystem components
DIVAST	Mathematical/dynamic	UK, University of Bradford	Coast	2/3D hydrodynamic model with simple phytoplankton module
ECOFATE	Mathematical/dynamic	Canada	Coast/Rivers	Contaminants and biota
Ecological Modelling for Windows (Ecowin)	Mathematical	Portugal	Coast/estuary/ rivers	Aquatic ecosystems and landscape
ECOPATH-ECOSIM-ECOSPACE	Mathematical	UK	Coast	Integrated mass balance model of fish dynamics
ECoS 3	Mathematical	UK, Plymouth Marine Laboratory	Principally estuary, can be modified for	Biogeochemical modelling framework

Modelling System	Tool Type	Country& Source	Area covered [coast/rivers]	Relevance to Ecosystem Modelling
			sea and river	
European Regional Seas Ecosystem Model (ERSEM)	Mathematical/dynamic	Denmark, Ecological Modelling Centre (VKI/DHI)	Coast	Generic model of pelagic and benthic ecosystems. The pelagic food web describes phytoplankton succession (in terms of diatoms , flagellates and microzooplankton) and mesozooplankton (omnivores and carnivores) predation.
General Ecosystem Model (GEM)	Mathematical/dynamic	US, Maryland International Institute for Ecological Economics	Wetland and shallow-water habitats	Driven largely by hydrologic algorithms for upland, wetland and shallow-water habitats, the model captures the response of macrophyte and algal communities to simulated levels of nutrients, water, and environmental inputs.
HABSCORE	Empirical	UK, Environment Agency	Rivers	Fish – salmonids
Hydrodynamic Eutrophication Model (HEM-3D)	Mathematical/dynamic	US, Virginia Institute of Marine Science	Coastal embayments, estuaries and tributaries	3-D numerical model which is an integration of a hydrodynamic model, a sediment transport model, and a water quality (eutrophication) model - currently being used to model larval behaviour
ISIS	Mathematical/dynamic	UK, Halcrow / HR Wallingford	Rivers	1-dimensional hydrodynamic with simple phytoplankton dynamics
Landscape Ecological Decision Support System	2D, expert system (conceptual)	Netherlands, DLO-Winand Staring Centre.	Rivers	Regional GIS model for landscape ecological evaluation of scenarios
LIFE (Lotic-invertebrate Index of Flow Evaluation)	Statistical-Empirical	UK, Environment Agency	Rivers	Correlation between flow rate and the status of macroinvertebrate species
MEDUSA	Empirical	UK	Rivers	Acidity on macrophytes, invertebrates, fish, birds
MIKE 3/11/21	Mathematical/dynamic	Netherlands, DHI	Rivers/Coast	1, 2 & 3-dimensional hydrodynamic models with simple ecological functionality. Eutrophication module covers growth of phytoplankton and zooplankton and benthic vegetation
Minder for Rivers	Empirical	UK	Rivers	Models risk of algal growth and eutrophication
Modelling Decision Support Framework (MDSF)	Decision Support System	UK, Defra & Environment Agency	Rivers	Flood estimation with potential to couple with geomorphology and ecosystems
MODULUS	Decision Support System	UK, Kings College London and partners		A spatial modelling tool for integrated environmental decision-making
QUAL-2EU	Mathematical/dynamic	US, USEPA	Rivers	Hydrodynamic model with simple algal simulation
Patuxent Landscape Model	Conceptual	US	Rivers	Simulation of fundamental ecological processes on the watershed scale, in interaction with land-use patterns.
Physical Habitat Simulation System (PHABSIM)	Mathematical/Empirical	US, USGS	Rivers	Simulation of microhabitat conditions in rivers as a function of streamflow and the relative suitability of those microhabitat conditions to aquatic life. Mostly developed for fish species.
POLest	Mathematical	UK, Proudman Oceanographic		Sediment transport model

Modelling System	**Tool Type**	**Country& Source**	**Area covered [coast/rivers]**	**Relevance to Ecosystem Modelling**
		Lab		
PROTECH	Mathematical/dynamic	UK, CEH	Rivers	Nutrients and phytoplankton
Proudman Oceanographic Laboratory Coastal-Ocean Modelling System (POLCOMS)	Mathematical/dynamic	UK, Proudman Oceanographic Laboratory	Coast	3-dimensional hydrodynamic model that interacts with ecological systems
RAMCO	Decision Support System	US, National Institute for Coastal and Marine Management	Coast	Prototype of a generic decision support system for coastal zone management
RBM10	Mathematical/dynamic	US	Rivers	Ecosystem (plankton, macrophytes, benthos) risk assessment tool
REHABSIM	Mathematical/dynamic	US Fisheries and Wildlife Service, Thomas Payne.	Rivers	Fully integrated programme for river hydraulics and aquatic modelling. An extensive conversion of the PHABSIM hydraulic and habitat simulation system.
RIVEG	Empirical	Netherlands	Rivers	Simulation of riparian habitats and biota
River Habitat Survey (RHS)	Empirical	US, Environment Agency	Rivers	Physical habitat monitoring and forecasting system
River System Simulator (RSS)	Mathematical/dynamic	Norway, SINTEF Civil and Environmental Engineering, Trondheim	Rivers	NMAG (hydropower simulation model); BIORIV (a model used to describe biological conditions in rivers, and the effect of changing physical conditions); and HABITAT (simulates physical habitat (living conditions) in rivers, and how this is affected by changes in streamflow.
RIVPACS	Empirical	UK, Environment Agency	Rivers	Aquatic habitat and macroinvertebrates. Used to predict what sort of communities should or could exist for given circumstances.
Salmon Productivity Model	Empirical	UK, APEM	Rivers	Calculation of changes to salmon productivity with changes in stream flow.
Shallow Sea Ecological Model (SSEM)	Not specified	Japan, Department of Civil Engineering, Yamaguchi University.	Coast	Fish and plankton
SimCoast	Decision-support system	UK	Coast	Expert system to support assessment of development on coastal processes and interactions
Spatial Modelling of the Environment (SME)	Not specified	US, Maryland International Institute for Ecological Economics	Not specified	Spatially explicit, dynamic simulation model of the ecosystem(s) within a particular landscape. An example is the Everglades Landscape Model (ELM).
SWARM	Empirical	US	Not specified	Multi-agent simulation platform. Has been used for plankton and landscapes.
Telemac/Tideway	Mathematical/dynamic	UK and France	Coast	Hydrodynamics and sediment transport
Trout Mortality	Empirical	Germany	Rivers	Water quality effects on trout
Flood Disturbance model	Compartment	US	Rivers	Simulates the effects of flood disturbance on food web interactions.

Appendix 5
Environment Agency R&D of Relevance to BSEIM

Projects that are Involved with or could Potentially have Inputs to Ecosystem Modelling, Habitat Suitability Models and Species Response Models

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
Environment Agency	Marc Naura River Habitat Survey Lead Region The Environment Agency Richard Fairclough House Knutsford Road Warrington WA4 1HG UK	**Midlands Coarse Fisheries & Crayfish Habitat Suitability Models**
Environment Agency	Marc Naura & Kevin Hall River Habitat Survey Lead Region The Environment Agency Richard Fairclough House Knutsford Road Warrington WA4 1HG UK	**Developing Habitat Suitability Models & Habitat Management Tools for Habitats Directive Species using RHS data**. Models to be developed using logistic regression and the possibility of developing neural networks to model habitat suitability. R & D project 2002-2005.
Environment Agency	B Howlett Water Resources	**Further validation of PHABSIM for the habitat requirements of salmonids.** To validate the Instream Flow Incremental Methodology (IFIM) using the Physical Habitat Simulation (PHABSIM) system as a tool to assess water resource issues for abstraction licences.
Environment Agency	J McEvoy Environmental Monitoring & Assessment Thames	**Response of European freshwater lakes to environmental and climatic change.** To study natural and anthropogenic factors that influence the temporal dynamics of plankton in Northern Europe to identify UK water resources at risk from climate change.
Environment Agency	C Extence Water Resources Anglian	**Use of macroinvertebrates to assess water flows.** To use the LIFE Index (Lotic Invertebrate Flow Evaluation Index) to develop a sound, robust method of evaluating impact of flow regimes on macroinvertebrates.
Environment Agency	T Jacklin Fisheries Midlands	**Fish community changes in recovering rivers.** To quantify the changes in fish community and population dynamics occurring in rivers of improving quality to facilitate wider understanding and acceptance of these changes by anglers and the public.

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
Environment Agency	K Broad Fisheries South West	**Relationship between juvenile salmonid populations and catchment features.** To improve the cost-effectiveness of fisheries management methods through improved measurement of catchment features
Environment Agency	D Clifton-Dey Fisheries Thames	**Swimming speeds in fish; phase 2.** To build on existing R&D work on swimming speeds to include other species such as barbel, grayling, perch. Pike, shad and community species.
Environment Agency	P Hickley Fisheries Midlands	**Use of biomanipulation to achieve improvements in water quality and habitat quality.** To develop guidelines for the use of biomanipulation based on current knowledge (using the precautionary principle where necessary) to enable better decisions on whether and how to use the technique.
Environment Agency	M Aprahamian Fisheries North West	**Effect of water quality on coarse fish movement and production.** To quantify the effect of water quality on coarse fish migration.
Environment Agency	K Broad Fisheries South West	**Fisheries habitat inventory - Phase 2.** To develop a two-tier River Fisheries Habitat Inventory to classify river habitat quality on a catchment scale for salmonids, based on (i) map-based features and (ii) field-based features.
Environment Agency	S Hughes Fisheries Midlands	**Methods for fishery rehabilitation - coarse fish**. To develop new methods of environmental restoration (other than water quality related) to enable the Agency to improve, develop and rehabilitate damaged coarse fish fisheries.
Environment Agency	D Clifton-Dey Fisheries Thames	**Swimming speeds in fish.** To carry out research into swimming speeds in fish to determine for a variety of species and life stages, both maximum and sustained speeds, and the effects of body size and temperature.
Environment Agency	I Johnson Fisheries Southern	**Decline of salmon in chalk rivers - Phase 2.** To investigate the factors contributing to the decline of salmon in chalk rivers to provide fisheries managers with suggestions on how to halt or reverse such decline in salmon stocks.
Environment Agency	D Martin Water Quality Midlands	**Modelling river corridors - the scientific basis for rehabilitation of urban rivers.** To examine the dependence of urban river ecosystems on flow, water quality and physical habitat to achieve a greater understanding of urban rivers.

Organisation	**Contact/Commissioning function/Area**	**Project title /description or objectives**
Environment Agency	B Brierley Environmental Monitoring & Assessment North East	**A review of ecology based classification systems for standing freshwaters.** To review ecologically based classification systems that would be applicable to temperate standing freshwaters over 0.5km2 surface area (these systems are likely to have been developed for lakes in Europe, North America or possibly southern hemisphere temperate zones.
Environment Agency	G Phillips Environmental Monitoring & Assessment Anglian	**Expert system for lake macrophytes.** To develop an "expert system" that relates aquatic macrophyte establishment and survival to various parameters in order to identify the probable development of vegetation in a shallow lake.
Environment Agency	G Daly Conservation Anglian	**River Habitat Survey (RHS) and Waterways Breeding Bird Survey (WBBS).** To develop links between bird survey data and RHS, in order to understand better species requirements and to enable appropriate implementation of river management practices.
Environment Agency	A Heaton Conservation Midlands	**Shad Conservation - Phase 2.** To (i) describe the spawning/juvenile habitat requirements of shad and (ii) review available information on effects of pollution on shad
Environment Agency	A Frake Conservation South West	***Ranunculus* in chalk rivers.** To develop and demonstrate more effective measures to protect and enhance chalk river ecosystems, to meet the Agency's obligations under the UK Biodiversity Action Plan.
Environment Agency	J Cecil Conservation Southern	The Ecology of two rare aquatic Molluscs, *Anisus vorticulus* & *Segmentina nitida.* To study the ecology of two rare aquatic Molluscs, *Anisus vorticulus* & *Segmentina nitida* in order to effectively contribute to the UK Biodiversity plan.
Environment Agency	T Sykes Conservation Southern	**Species management Phase 3 - Southern Damselfly conservation.** To maintain and enhance the current status of the species in the UK in order to prevent further loss of breeding populations in England and Wales. The research will specifically examine the larval ecology, adult behaviour, population dynamics and habitat
Environment Agency	J Tinsley Conservation Head Office	**Technical services – Biological Records Centre.** To obtain information on the status and distribution of flora and fauna in the UK from the Biological Records Centre national database that will be of use to Agency staff in undertaking their duties.
Environment Agency	T Jones Conservation	**Otter biodiversity action plan.** To co-ordinate Agency and other relevant work to fulfil the Agency's

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
	Wales	role as contact point under the Biodiversity Action Plan
Environment Agency	P Raven Conservation Head Office	**Using RHS to derive river habitat objectives.** To establish the feasibility of using RHS and other information to set river habitat objectives at a policy, strategic and operational level.
Environment Agency	G McMellin Fisheries Wales	**Investigation of land use impacts on fisheries.** To assess the impacts of soil erosion and siltation on gravel beds and spawning success of salmonid and coarse fish to provide best practice guidance on siltation detection and measurement.
Environment Agency	National Salmon and Trout Fisheries Centre Environment Agency Wales Rivers House St Mellons Business Park St Mellons Cardiff CF3 0LT Telephone: 02920 770088 Fax: 02920 798555 e-mail: rob.evans@environment-agency.gov.uk (Cardiff) ian.davidson@environment-agency.gov.uk (DSAP,Buckley) Fisheries R & D website further details available at: http://intranet2.ea.gov/Organisation/National/NSTFC/index.htm	On going Projects:2001/2002 *Salmon, Trout and Grayling* River Fisheries Habitat Inventory Phase 2. Catchment-scale classification of salmonid habitat quality, leading to an integrated framework for the Fisheries Classification System, HABSCORE methodology, Salmon Life-cycle Model, and Spawning Target procedures. Investigation of land use impacts on fisheries. Better understanding of the sources and fates of fine sediment in rivers, and its effects on salmonid populations. Factors affecting the carrying capacity of salmonids in rivers. Improved habitat modelling, leading to better-informed management decision making. Factors affecting coarse fish recruitment Phase 2. To understand the factors affecting recruitment of coarse fish in order to improve the effectiveness of management of riverine coarse fisheries *Coarse fish* Factors affecting coarse fish recruitment Phase 2. To understand the factors affecting recruitment of coarse fish in order to improve the effectiveness of management of riverine coarse fisheries. Changing Fishery Performance in Recovering Rivers.

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
		A long term programme of strategic research which, will enable the Agency to characterise, quantify and understand the changes in fish community and population dynamics which occur in rivers with improving water quality, recovering from heavy industrial and domestic pollution (recovering rivers). In order to facilitate wider understanding and acceptance of these changes by anglers and the general public. *Cross Functional Projects*. Flow criteria for fisheries (Water Resources funding). Protection of migratory salmonid stocks in the face of increasing demands for abstraction
Centre for Intelligent Environmental Systems. Staffordshire University.	Prof. Bill Walley. John Murray-Bligh (Environment Agency Contact) N.B. Details and further information can be found at http://www.soc.staffs.ac.uk/research/groups/cies	**Assessment of river nutrient and macroinvertebrate quality correlation in England and Wales using artificial intelligence techniques.** (Environment Agency, R&D Project, £4,830, 2002). **Development of Bayesian Belief Network systems and applications.** (Staffordshire University Research Initiative, £19,000, 1997-ongoing). **Collaboration with the Agricultural University of Uppsala to develop AI-based environmental monitoring systems for Sweden**. (2001-ongoing). **Applications of artificial intelligence in river quality surveys** (Environment Agency, £90,000, 1995-98). Technical Reports produced: Distribution of macroinvertebrates in English and Welsh Rivers. Applications of artificial intelligence for the biological surveillance of river quality.
NERC Thematic programme	Science Co-ordinator: Professor Ian Douglas, School of Geography, University of Manchester, Manchester. M13 9PL (tel: 0161 275 3462; fax: 0161 275 7878; email: ii.douglas@man.ac.uk) Programme Administrator: Dr Catrin Yeomans, NERC, Polaris House, North Star Avenue, Swindon SN2 1EU	LOCAR (Lowland Catchment Research) The LOCAR programme aims to improve the science required to support current and future management needs for permeable lowland catchments through an integrated and multi-disciplinary experimental and modelling programme.

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
	(tel: 01793 442504; fax: 01793 411502; email: cvy@nerc.ac.uk For general enquiries (Environment Agency) please contact Rachel Fleming, Tel: 01454 878862 Email: Rachel.fleming@environment-agency.gov.uk Further information on LOCAR can be found at: http://www.nerc.ac.uk/funding/thematics/locar/index.shtml Successful project out-line bids can be found at: http://www.nerc.ac.uk/funding/thematics/locar/news.shtml	*Scientific Aims*: To develop an improved understanding of hydrological, hydrogeological, geomorphological and ecological interactions within permeable catchment systems, and their associated aquatic habitats, at different spatial and temporal scales and for different land uses. To develop improved modelling, database and GIS tools to inform and support the integrated management of lowland catchment systems. These aims will be achieved through the study of: The surface and near-surface environment - runoff, recharge and material transport; Groundwater processes in lowland catchments; Physical, chemical and biological processes within the valley floor corridor; In-stream, riparian and wetland habitats and their dependence on flow regimes; The impacts of society on the natural environment. Broader Programme Objectives: To provide an underpinning science base for the requirements of the UK and CEC for environmental protection within a framework of sustainable and integrated river basin management; To establish flagship sites as a basis for long-term monitoring, to provide the necessary data to define natural variability and response to environmental change;
Defra (Information on research projects obtained from http://www.defra.gov.uk/research/researchfrm.htm) N.B. code before title is Defra project code.	ADAS Consulting Ltd Central Science Laboratory	**BD0405 : Management of ditches in arable fenland for wildlife and drainage**.
Defra	Silsoe Research Institute	**BD1310 Water regime requirements and response to hydrological change of grassland plant communities (old BD0225)**
Defra	CEFAS	**SF0229 : Habitat utilisation and population dynamics in wild**

Organisation	Contact/Commissioning function/Area	Project title /description or objectives
		salmonids
Defra	CEFAS	**SF0231 : Habitat selection and the distribution of migratory salmonids in river systems**
Scottish Natural Heritage	SNH 5 Anderson Place Edinburgh Scotland Website contact: http://www.snh.org.uk	Many Habitat and species projects ongoing. Examples of projects are shown below: **F99/LC02 Distribution and conservation status of the Freshwater Pearl Mussel, *Margaritifera margaritifera,* in the Isle of Lewis and Harris.** **F99/LD04 Glencoe habitat survey and assessment.** **F99/LF05 The geomorphological character of the River Dee and the significance of that character on its Natura species and suitability for active river engineering.** **F99/PA04 Status and habitat requirements of the otter in the River Spey catchment.**
SNIFFER	SNIFFER 11/13 Cumberland Street Edinburgh EH3 6RT Contacts: Website: http://www.sniffer.org.uk Rebecca Badger, Research Manager (Water Framework Directive) Tel: 0131 524 9743 rebecca@sniffer.org.uk	w(99)09 Safeguarding Natura 2000 rivers in the UK w(99)61 The effect of riparian forest management on the freshwater environment

Appendix 6
BSEIM Project Specification “Form A” Templates

BSEIM 1

Title	BSEIM Toolbox Phase 1
Objective	To establish a BSEIM toolbox containing best practice in data collation and ecosystem impact prediction using currently available techniques.
Background and scientific context	Broad scale ecosystem impact modelling is required as part of the fluvial and estuarine/coastal flood management planning process (CFMP, SMP etc.). No detailed guidance is currently available to help with definition of data gathering and predictive modelling of likely impacts/benefits. In the absence of a robust ecosystem modelling methodology the user community has requested that a toolbox of current best practice be collated and disseminated until such time as an appropriate suite of modelling tools becomes available.
Outline work programme	To include basic data and guidance for qualitative ecological impact assessments: • Descriptors of baseline ecosystems (aquatic, riparian, wetland); indicator habitats, communities and species; sources of data; AQC procedures etc. • Suggested approaches to ecosystem impact assessment for catchments and coastal waters, • Key texts on bottom up and top down predictive approaches for indicator groups • Methodologies to specify constraints and opportunities • Develop appropriate user support tools to ensure the appropriate application of BSEIM tools.
Outputs	A BSEIM toolbox report that can be widely disseminated to the user community.
User benefits	A consistent "good practice" methodology, as requested by the user community that gives users the confidence to apply best available data and techniques in a robust and representative form.
Key linkages	CFMP and SMP guidance documents; Defra FCD R&D programme; Environment Agency RHS initiative; implementation of Water Framework and Habitats Directive work; UK Life in Rivers, UK Marine SAC Project; Estuaries Research Programme 2.
Procurement; indicative costs	£80k budget. Need for quick turn-round to support ongoing flood planning initiatives would suggest consortium approach. 6 month project.

BSEIM 2

Title	Hydro-geomorphological Model Development
Objective	To provide initial guidance and specification of suitable fluvial and coastal hydro-geomorphological modelling platforms/concepts on which to base future ecosystem impact models.
Background and scientific context	Recent studies have suggested that the hydro-geomorphological drivers of ecosystem change require further development before they can be consistently and reliably used as a basis for broad scale ecosystem impact modelling. Moreover, coastal and fluvial systems have discrete interactions that have resulted in differentiation in methodologies and outputs. A study is required to establish the most suitable techniques for prediction of fluvial and estuarine/coastal hydro-geomorphological change, which can then be used as a basis for ecosystem impact modelling. It is likely that GIS based, geographically and spatially referenced techniques will be the most suitable forms of data outputs for BSEIM.
Outline work programme	A number of elements will be required: • Definition of data input requirements for BSEIM tools - Assessment of outputs from hydrological, hydrodynamic and geomorphological models and consideration of the spatial and temporal data requirements for ecosystem modelling. • Determination of methods and formats for storing and sharing data. • Further research in hydrology, hydrodynamics and geomorphology to ensure that outputs produce data at a suitable spatial and temporal resolution to be useful for ecosystem and ecological modelling. • Development of specification and case study outputs for hydro-geomorphological modelling tools on which to base ecosystem impact assessments. • Production of a modelling framework that will support long-term ecosystem impact modelling tool development.
Outputs	A specified modelling framework with supporting case studies for both fluvial and estuarine/coastal systems. The framework will include identification and initial coding of modelling techniques on which future development will take place. At this time it is likely that greater emphasis should be given to fluvial systems, with estuarine and coastal developments channelled through the ERP2 and coastal processes

	themes. The outputs must link directly to and be consistent with BSEIM 3.
User benefits	A hydro-geomorphological modelling framework will provide the fundamental basis on which BSEIM can be based.
Key linkages	The first stages of model development must ensure the integration of the hydro-geomorphological and ecological processes (see also BSEIM 3 specification). Key linkages for fluvial systems include the work on distributed hydrological/geomorphological models (UKWIR, Agency), Agency physical quality objectives and RHS, NERC LOCAR and CHASM. Estuarine and coastal linkages include ERP2, Futurecoast, sediments and habitats concerted action, and Agency RHS.
Procurement; indicative costs	£100k. Need for quick turn-round to support ongoing flood planning initiatives would suggest consortium approach. Integration with BSEIM 3 could be enhanced by development of project within co-ordinated project portfolio using same multi-disciplinary team. 1 year project.

BSEIM 3

Title	Broad-scale Ecosystem Impact Model Development – Phase 1
Objective	Development of an initial BSEIM modelling platform that forms the basis of the strategic modelling tool. The model should establish a working framework that allows simulation of ecosystem change, on which the medium and long term R&D programme can build.
Background and scientific context	The BSEIM R&D programme has identified a strategic gap in the UK modelling capability to simulate the potential for change in ecosystems resulting from flood management practices. Three short term projects are specified (BSEIM 1 to 3) to provide initial guidance and a framework for future model development. This project has the aim of developing a working model framework on which more detailed medium and long term model development can be based. The model must take current best practice in this discipline and build on it to establish a robust modelling platform, integrating hydrogeomorphology and ecological disciplines. To do this the research must first establish the most appropriate spatial and temporal scales of baseline description and the describe known ecological process dynamics (which can be used to parameterise the later model). A modelling framework will then be developed recognising current best practice and through research into contemporary/novel ecosystem simulation.
Outline work programme	The work programme should be undertaken in three stages, which will have to be undertaken concurrently to meet the two year deadline: **a) Development of Suitable Ecosystem Baseline Description** • Identification of indicator habitats, communities and species for catchments and coastal zones subject to flood management policy appraisals • Identification of the most suitable spatial and temporal resolution for habitat, community and species mapping at a catchment and coastal zone scale • Development of habitat mapping tools to provide suitable data, preferably using pre-existing and agreed methodologies. These should be compatible and integrated with other catchment mapping techniques and technology. This may include floodplain mapping using CASI and

	LIDAR for flood levels, ecology etc.. • In the absence of existing data of sufficient resolution, a pragmatic short term solution is required to CFMP and CHaMP assessments. Guidance on the collation and assessment of data should be provided as inputs to BSEIM toolbox phase 1. **b) Interaction and Dynamic Evolution of Aquatic, Riparian and Wetland Ecosystems** • Research into the lifestage dynamics of key indicators habitats, communities and species in relation to flood flows and inundation and/or from geomorphological change (if these are found to be forcing functions). Attention should initially focus on the key species identified in EC Directives and UK regulations, with emphasis moving to a more holistic analysis after the first tranche of work, recognising the inter-dependence of aquatic and wetland ecosystems. • Better understanding of relationship between fluvial flooding and ecosystem function. What effect do changes in habitat availability and rate/longevity of inundation have on aquatic and wetland ecosystems? Scoping for medium term R&D field trials of ecosystem effects. • Better understanding of relationship between coastal flooding and ecosystem function. What effect do changes in habitat availability and rate/longevity of inundation have on aquatic and wetland ecosystems? Scoping for medium term R&D field trials of ecosystem effects. **c) Development of Ecosystem Modelling Approaches** • Description of modelling tools appropriate for immediate application for broad-scale modelling of catchments and coastal zones – simple mathematical, empirical and/or conceptual tools (for input to BSEIM toolbox phase 1). • Study to determine most suitable spatial and temporal scales for predictive capabilities for range of quantitative BSEIM tools and specification of the most promising combinations (integrated with the output from BSEIM 2). • Development of adaptive management approach that has nested broad-scale to local reach assessment format, for incorporation into BSEIM toolbox in phase 2. • Identification of basic structure and architecture of quantitative modelling systems, including a generic framework with specific modules to

	encourage further development. • Pilot study to describe most appropriate modelling tools for simulation of identified catchment-based indicators of habitats, communities and/or species – using sample catchment. • Pilot study to describe most appropriate modelling tools for simulation of identified coastal zone indicators of habitats, communities and/or species – using sample coastal zone. • Collation of novel techniques such as bayesian belief, neural networks, fuzzy logic, artificial intelligence, and specification of advantages/disadvantages of each for BSEIM applications (for potential medium term R&D) • Specification of framework for user-friendly modelling tool interface for incorporation into BSEIM toolbox phase 2 • Specification of decision-support/expert system platform for incorporation into BSEIM toolbox phase 2.
Outputs	Initial spatially and temporally referenced modelling frameworks for fluvial and estuarine/coastal ecosystems that have the ability to predict relative changes in ecosystem integrity. They will form the basic structure on which more detailed and robust models can be built over the medium to longer term.
User benefits	At present there are no accepted methodologies for BSEIM in the UK. Users have requested that the work specified here progresses rapidly to allow future prediction of ecosystem impacts with greater confidence. The framework specified here can deliver appropriate modelling tools in a reasonable timescale.
Key linkages	Most of the FCD R&D hydrology and geomorphology outputs will have some bearing on ecosystem impact assessment and must be co-ordinated (mainly with the BSM, Processes and Engineering Themes). This project must integrate with work by Defra, the Agency, SNIFFER, English Nature, CCW etc. to support the Habitats and Water Framework Directives. This should ensure minimal duplication of effort and encourage development of consistent and inter-related assessment tools.
Procurement; indicative costs	£300k. Need for quick turn-round to support ongoing flood planning initiatives would suggest consortium approach. 2 year project.

Appendix 7
List of Acronyms and Glossary

List of Acronyms

ABMs	Agent-Based Models
AI	Artificial Intelligence
BAPs	Biodiversity Action Plans
BNs	Bayesian or Belief Networks
BPEO	Best Practicable Environmental Option
BSEIM	Broad Scale Ecosystem Impact Modelling
BSM	Broad-scale Modelling
CAMS	Catchment Abstraction Management Plans
CAs	Cellular Automata
CASI	Compact Airborne Spectrographic Imager
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CEH	Centre for Ecology and Hydrology
CFMP	Catchment Flood Management Plan
CHaMP	Coastal Habitat Management Plan
CHASM	Catchment Hydrology And Sustainable Management
CIRIA	Construction Industry Research and Information Association
CMLs	Coupled Map Lattices
COASTPACS	RIVPACS-type model derived for coastal/offshore sites
CROW	Countryside and Rights of Way Act 2000
cSAC	candidate Special Area of Conservation
CSERGE	Centre for Social and Economic Research on the Global Environment
DBN	Dynamic Bayesian or Belief Network
Defra	Department for Environment, Food and Rural Affairs
DETR	Department of Environment, Transport and the Regions (now Defra)
DHI	Danish Hydraulic Institute
DIVAST	Depth Integrated Velocities and Solute Transport (model)
EC	European Commission
EIA	Environmental Impact Assessment
EMPHASYS	Estuarine Morphology and Processes Holistic Assessment System
EMP	Estuary Management Plan
EPSRC	Engineering and Physical Sciences Research Council
ERP	Estuaries Research Programme
EU	European Union
FAP	Fisheries Action Plan
FCDPAG	Flood and Coastal Defence Project Appraisal Guidance
GEMBASE	General Ecosystem Model for the Bristol Channel and Severn Estuary
GIS	Geographical Information System
Habscore	Environment Agency salmonid modelling system
HAP	Habitat Action Plans
IBMs	Individual-based Models
ICZM	Integrated Coastal Zone Management
IEEM	Institute of Ecological and Environmental Management
ISIS	Open Channel and Catchment Modelling System
JNCC	Joint Nature Conservation Committee
LEAP	Local Environment Agency Plan
LIDAR	LIght Detection And Ranging
LIFE	Lotic-invertebrate Index of Flow Evaluation
LOCAR	Lowland Catchment Research
LOIS	Land Ocean Interaction Study
MAFF	Ministry of Agriculture, Fisheries and Food (now Defra)
MCE	Multi-Criteria Evaluation
MDSF	Modelling Decision Support Framework
MLIS	Marine and Land-based Inputs to the Sea, a division of Defra
MNCR	Marine Nature Conservation Review
MTR	Mean Trophic Rank
NERC	Natural Environment Research Council
NMMP	National Marine Monitoring Plan
NNR	National Nature Reserve

OSPAR	Oslo and Paris Convention 1992
PHABSIM	Physical HABitat SIMulation
PPG	Planning Policy Guidance
PQO	Physical Quality Objective
R & D	Research and Development
RBMP	River Basin Management Plan
RHS	River Habitat Survey
RIVPACS	River InVertebrate Prediction And Classification System
SAC	Special Area of Conservation
SAP	Salmon Action Plan
SET	Science, Engineering and Technology
SINC	Sites of Importance for Nature Conservation
SMP	Shoreline Management Plan
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SWARM	A software package for multi-agent simulation of complex systems
UKWIR	UK Water Industry Research Ltd
US EPA	US Environment Protection Agency
WLMP	Water Level Management Plan

Glossary

Anthropogenic change	Change brought about by the influence of human activity.
Baseline	A set of critical observations or data used for comparison or as a control.
Biogeochemistry	Science that deals with the partitioning and cycling of chemical elements and compounds between the living and non-living parts of an ecosystem.
Conceptual models	Similar to 'Mathematical' but less precise. Variables are represented as abstract entities subject to, and themselves exerting a number a specified influences, rather than realistically in terms of biophysical properties. Some assessment of the relative strengths of these influences is usually required. Often represented by network flow diagrams.
Decision support tool	A database and/or expert system that helps a user make a decision. This may include, for example, information on current technical best practice for ecosystem assessment, places to search for data, and methodologies used for requesting and analysing model-derived outputs (how to use modelling tools and how to interpret data).
Deterministic	In terms of models, based on physical processes.
Dynamic	Marked by usually continuous and productive activity or change.
Empirical – statistical models	Data-based models. Data are collected, from which correlations and covariances are determined between the relevant variables. These covariances are then used to assess the potential impact of possible variable changes on other variables to make predictions.
Geomorphology	Science that deals with the relief features of the land.
Heterogeneity	Comprising dissimilar or diverse constituents.
Hierarchy	A graded or ranked series.
Homogenous	Of uniform structure or composition throughout.
Hydrodynamics	Science that deals with the motion of fluids, in this case water, and the forces acting on solid bodies immersed in water and in motion relative to them.
Hydrology	Science dealing with the properties, distribution, and circulation of water on and below the earth's surface.

Mathematical models	Logical relationships between variables are postulated – often in the form of dynamic equations – which represent a formalization of hypothesised dependencies between variables. The consequences of these formalized hypotheses can then be explored rigorously using analytic and/or simulation methods.
Probabilistic	Relating to the probability that a given event will occur.
Proprietary	Something that is used, produced, or marketed under exclusive legal right of the owner, eg commercial software.
Resolution	Spatial or temporal scale.
Scaling	Applying to a different (spatial) scale, either larger or smaller.
Soft engineering	Use of ecological principles and practices to achieve engineering solutions (typically to stabilise banks and shorelines) by using native plants and materials other than concrete/steel sheeting to improve ecological features without compromising engineering integrity.
Stakeholder	An individual, group or organisation with a vested interest.
Stochastic	Modelling approach involving prediction of a probability.

Nature Conservation Designations

International Designations:

Ramsar site	Wetlands protected under the Ramsar Convention
SAC	Special Area of Conservation under the EU Habitats Directive 92/43/EEC (candidate areas (cSAC) are the same for purposes of this report)
SPA	Special Protection Area under the EU Birds Directive 79/409/EEC

National Designations:

NNR	National Nature Reserve under the Wildlife and Countryside Act, 1981
SSSI	Site of Special Scientific Interest under the Wildlife and Countryside Act, 1981

Non-statutory Designations:

SINC	Site of Importance for Nature Conservation, as designated by the Local Authority