Review of existing UK developed DSS tools

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Task Leader Partner Name
Caroline McGahey HRW

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<tr>
<td>Lead Authors</td>
<td>Caroline McGahey &amp; Paul Sayers,</td>
</tr>
<tr>
<td>Contributors</td>
<td>Paul Dunning &amp; Darren Lumbroso</td>
</tr>
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SUMMARY

Long-term planning is an integral part of developing sustainable flood risk management policies and intervention measures. In particular, it enables decision makers to explore strategies, set targets, question the status quo and determine the merits of innovative ideas.

The scientific outcome of Task 18 will be a conceptual framework for long term planning for flood risk management that enables information on flood risks and management options to be integrated in support of identifying preferred future management strategies. The conceptual framework will be enacted within a prototype decision support tool that enables the decision maker to integrate multiple and complex relationships between natural hazards, social and economic vulnerability, the impact of measures and instruments for risk mitigation (infrastructure provision, vulnerability reduction) in support of flood risk management planning in the long term.

This report constitutes Research Output 5 which stems from the work undertaken in Activity 1, Action 2, which is “a review of the existing system tools to support long term flood risk management”. It involves reviewing existing international “best practice” and the advantages and disadvantages of the various national approaches and DSS tools. This report focuses on DSS tools developed in the United Kingdom and forms a useful basis for the overall Task 18 DSS review, Deliverable 18-1.

Eleven existing UK developed DSS tools are reviewed. The detail of these reviews varies, as in some instances HR Wallingford was actively involved in the tool development and for others, the review is based on information in the public domain. The tools are reviewed in terms of:

1. **Content** such as representation of the flood risk system; measures and instruments; scenarios of external change; spatial and temporal scales and results
2. **Data and methods** covering input data; methods and uncertainty.
3. **Presentation** including target end-users and visualisation
4. **Technological realisation**, for example, software architecture and
5. **Other** such as support and applications strengths and weaknesses

The principal findings are that the DSS:

1. should be decision specific rather than attempting to solve too many things;
2. the information provided should be ‘rich’ i.e. enabling the user to explore the basis of the evidence presented;
3. should be appropriately flexible;
4. should have an appropriately open/closed architecture for the decision at hand and the mode of use;
5. should be modular where possible i.e. having recourse to use results of external models or to use the embedded default methods;
6. should be scale independent (spatial and temporal);
7. should reflect the policy context e.g. with the move towards flood risk management, the DSS tools should incorporate risk-based methods;
8. should reflect a probabilistic approach to flood risk as this is strongly advocated in the UK;
9. should place high importance on the presentation of outputs as these should be clear whilst reflecting the complexity of the underlying analysis; and
10. should explicitly handle uncertainty and provide associated guidance on the interpretation of this information.

The UK has seen a wide uptake and use of two DSS tools in recent years, one for strategy planning (MDFS, Chapter 2) and one for National Flood Risk Assessment (NaFRA, Section 6.1). The reasons for this relate to provision of user training and support, ongoing software maintenance, including the
release of new versions, and the use of national data sets. In addition, the use of these DSS tools is advocated by the appropriate authorities to their consultants.
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1. Introduction

1.1 Background

Task 18, Activity 1, Action 2 involves a review of existing tools to support long-term flood risk management. This includes a review of existing international “best practice” and the advantages and disadvantages of the various national approaches and DSS tools. The outputs for Action 2 include the overall DSS review, Deliverable 18-1, which draws on two Research Outputs:

1. Research Output 5 - the UK DSS Review; and
2. Research Output 6 - the Netherlands DSS review.

This report constitutes Research Output 5 which provides the UK perspective on existing DSS tools, developed by or in collaboration with UK persons.

Deliverable 18-1 explores the literature for definitions of what a DSS tool is and what it consists of. Based on this exploration, the following definition has been adopted for FLOODsite Task 18:

“A DSS is a computer-based approach or methodology supporting individual or collective decision makers in the solution of semi-structured problems. It uses a database, models and a graphical user interface and provides its results mainly in a graphical way. The development of such a system may involve the users from the initial development stages through to development completion and onwards.”

1.2 Review criteria

The DSS tools reviewed in this report all have different decisions which they support, different end users and, in some instances, they are designed for educational purposes. For this reason, it is difficult to establish a consistent set of review criteria as each DSS tool will score well in the categories which mirror its design requirements. For example, a DSS tool designed for application to a specific site may not be readily extendable to other sites.

The review criteria which have been adopted for all DSS tools in Task 18 are as set-out in Deliverable 18-1. These are based on five broad categories: content; data and methods; presentation; technological realisation; and other. These are sub-divided into sub-categories representing different features of the tools and summarised in Table 1 below. For the further detail, see Deliverable 18-1.
Table 1: Summary of DSS Review Criteria (adapted from Deliverable 18-1)

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Review Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Content</td>
<td>1.1 Flood risk system</td>
<td>In FLOODsite, the Source-Pathway-Receptor-Consequence model (Sayers et al., 2002) has generally been accepted. This sub-category considers the degree to which the DSS tool characterises the flood risk system in terms of the SPRC model. Ideally, the tool would include a module for each term e.g. the Pathway module represents flow in the river, over defences and across the floodplain, whereas the Receptor module concerns itself with elements which may be harmed by flooding e.g. people, houses.</td>
</tr>
<tr>
<td></td>
<td>1.2 Measures and instruments</td>
<td>This involves the degree to which the DSS tool enables the user to represent interventions i.e. measures and instruments (Task 12) which may form part of an overall integrated flood risk management strategy. Measures are direct physical interventions e.g. dike raising whereas policy instruments are interventions triggering mechanisms which can lead to reducing flood risk e.g. improved publicity and education on flooding.</td>
</tr>
<tr>
<td></td>
<td>1.3 Scenarios of external change</td>
<td>This involves the degree to which the DSS tool enables the user to represent future scenarios, where a scenario is defined as “a plausible description of a situation, based on a coherent and internally consistent set of assumptions”. For example, a scenario based on high market growth may be associated with high climate change, high population growth and urbanisation. Different DSS tools may allow for different degrees of complexities e.g. the number of parameters which may be varied.</td>
</tr>
<tr>
<td></td>
<td>1.4 Spatial and temporal change</td>
<td>Timescales are relevant as the DSS tool is for long-term planning. The tool needs to assess the flood risk through time, which could include evaluating risk at discrete epochs or use of continuous simulation. Similarly, spatial scales are relevant as the DSS tool should ideally be applied at any scale, typically made possible through use of GIS or MapInfo. The aim is to establish the ability of the tool to model these different scale options and to identify any restrictions.</td>
</tr>
<tr>
<td></td>
<td>1.5 Results</td>
<td>This involves assessing the nature of the DSS outputs e.g. can the user access the Source loadings, Pathway inundation extents for a given system state, Receptor impacts such as environmental, economic and social vulnerability, Consequences such as spatial risk etc.</td>
</tr>
<tr>
<td>2. Data and methods</td>
<td>2.1 Input data</td>
<td>DSS tools are largely data driven e.g. water levels, ground models, receptor information etc. The nature and quality of the data are considered.</td>
</tr>
<tr>
<td></td>
<td>2.2 Methods</td>
<td>What methods are incorporated within the DSS to evaluate the SPRC system model from Source loading through to spatial risk? These may include embedded or linked models, data from external analyses, other. The integration method to evaluate the overall risk is essential.</td>
</tr>
<tr>
<td></td>
<td>2.3 Uncertainty</td>
<td>Understanding uncertainty is essential to the decision making process – and thus each DSS tool is considered in terms of what uncertainty methods and/or information it provides. Here, uncertainty is defined as the difference between assessment of some factor and its ‘true’ value.</td>
</tr>
<tr>
<td>3. Presentation</td>
<td>3.1 Target end-users</td>
<td>This establishes which users are being addressed and their decisions. DSS tools may assist with decisions on a number of levels e.g. strategy vs local planning or societal vs professional decisions. Ideally the DSS should operate on all levels and consider the professional context.</td>
</tr>
<tr>
<td></td>
<td>3.2 Visualisation</td>
<td>The decision makers will need to access the results in a useful visual format which is transparent to all i.e. both experts and non-experts. Note: users have the option of which DSS tool to use so a tool with good visualisation techniques may be favoured.</td>
</tr>
<tr>
<td>4. Technology</td>
<td>4.1 Software architecture</td>
<td>The DSS end-to-end process is typically complex, with many routines, methods, models and databases. Thus, the software architecture is critical. This criterion considers modularity, embedded models, interfaces, development environment, coding language and accessibility etc.</td>
</tr>
<tr>
<td>5. Other</td>
<td>5.1 Application, strengths, weaknesses</td>
<td>Addresses software support and future development and maintenance e.g. what level of support was provided? Was it sufficient to ensure the ongoing use? Would the tool have benefited from improved roll-out and support planning? Who has ownership?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Application considers the acceptance of the system and its application in practice. The strengths and weaknesses highlight the key elements from the review as well as any items not explicitly covered.</td>
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</table>
1.3 UK DSS Tool Development

In the UK, a variety of DSS tools have been developed for different purposes. These can broadly be divided into three categories:

(i) project specific tools not designed for application to other areas;
(ii) educational tools to familiarise people with flood related issues; and
(iii) generic tools for ongoing use in the strategic planning for any site.

Table 2 provides a summary of the tools considered and the level of detail provided for each, where the latter is dependent on the availability and access to information on the tools.

These DSS tools are reviewed against the criteria set-out in Section 1.2 in the subsequent sections.

Table 2: DSS Tools under review by the UK partners

<table>
<thead>
<tr>
<th>DSS Acronym</th>
<th>Full name</th>
<th>Level of Detail</th>
<th>Design category</th>
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<tr>
<td><strong>DSS tools</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1. MDSF</td>
<td>Modelling Decision Support Framework</td>
<td>High</td>
<td>(iii)</td>
</tr>
<tr>
<td>2. DESIMA</td>
<td>Decision Support for Integrated Coastal Zone Management</td>
<td>Medium</td>
<td>(i)</td>
</tr>
<tr>
<td>3. FloodRanger</td>
<td>FloodRanger</td>
<td>Medium</td>
<td>(ii)</td>
</tr>
<tr>
<td>4. Eurotas</td>
<td>The EUropean River Flood Occurrence &amp; Total Risk Assessment System</td>
<td>Medium</td>
<td>(i)</td>
</tr>
<tr>
<td><strong>RASP-based DSS tools</strong></td>
<td></td>
<td></td>
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<tr>
<td>5. NaFRA</td>
<td>National Flood Risk Assessment</td>
<td>High</td>
<td>(iii)</td>
</tr>
<tr>
<td>6. PAMS</td>
<td>Performance-based Asset Management Systems</td>
<td>High</td>
<td>(iii)</td>
</tr>
<tr>
<td><strong>Other non-UK specific tools</strong></td>
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<td></td>
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<tr>
<td>7. RAMFLOOD</td>
<td>RAMFLOOD</td>
<td>Low</td>
<td>(i) / (iii)</td>
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<tr>
<td>8. ANFAS</td>
<td>ANFAS</td>
<td>Low</td>
<td>(iii)</td>
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<td>9. MIKE11 DSS</td>
<td>MIKE11 DSS</td>
<td>Low</td>
<td>(iii)</td>
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<tr>
<td>10. EFAS</td>
<td>European Flood Alert System</td>
<td>Low</td>
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2. MDSF

2.1 Brief description

The Modelling and Decision Support Framework (MDSF) was developed by HR Wallingford, Halcrow, the Centre for Ecology and Hydrology and the Flood Hazard Research Centre. It was created to support the implementation of Catchment Flood Management Plans (CFMPs), a major initiative of the Department for Environment, Food and Rural Affairs (Defra), the Welsh Assembly Government and the Environment Agency (EA) of England and Wales. A CFMP is a high-level strategic planning tool through which the EA will seek to work with other key decision-makers within a river catchment to identify and agree policies for sustainable flood risk management. In practice, the MDSF is also suitable for use with Shoreline Management Plans (SMP) which provide a large-scale assessment of the risks associated with coastal processes and hence present a long-term policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner. Other MDSF applications include strategy studies, pre-feasibility studies and other similar appraisals.

2.2 Contents

2.2.1 Criterion “Flood risk system”

MDSF incorporates the SPRC framework through inclusion of source terms and pathway and receptor modules as well as management response and decision support modules. For example:

- The MDSF framework anticipates the use of model results, generated externally and imported into MDSF as source terms. This includes the in-river and coastal water levels and/or the flood depths and associated probabilities over the floodplain.
- The pathways module includes flow across the Digital Terrain Model (DTM) and simple representations of the defence information e.g. defended or undefended.
- The receptor module includes, for example, population, property type, agriculture land-use and social vulnerability indices.
- The management response module enables user intervention to alter the source, pathway and receptor terms to best represent the proposed measures or combinations of measures. These edits are typically undertaken in the external hydraulic model or the MDSF ArcGIS environment – as appropriate to the measure.
- The decision support module assists in evaluating multiple cases, aggregating results and providing economic metrics and uncertainty information for the various cases.

Note that the MDSF software does not do any modelling nor does it make any decisions.

2.2.2 Criterion “Measures and Instruments”

The MDSF enables system interventions e.g. physical measures and/or policy instruments through editing the various SRPC system components. For example:

- changing the source terms through modification to the external hydraulic models e.g. increased in-line storage, operation of sluice gates etc.
- changing the pathway and receptor terms within the ArcGIS environment to reflect structural measures e.g. altering the DTM to increase storage or expanding the defended areas to reflect raised defences and non-structural measures e.g. changes in public attitudes and preparedness can also be represented through changes to the National Social Vulnerability base data set.

More than one data set may be changed at any stage, thus allowing for combinations of measures. To assist policy evaluation, MDSF aggregates and compares the calculation results from property damages, agriculture damages and population affected by flooding.
2.2.3 Criterion “Scenarios for external change”

The MDSF enables the user to model scenarios for external change through editing:
- the source terms in the external models e.g. climate change leading to increased flows;
- the pathway terms within the MDSF ArcGIS environment e.g. altering the DTM and Crest Level data to reflect land subsidence;
- the receptor terms within the MDSF ArcGIS environment e.g. population density, urbanisation etc.

2.2.4 Criterion “Spatial and temporal scales”

The MDSF is not restricted by spatial or temporal scale. Spatial applications may include catchment, sub-catchment and river reach and it may be used for inland catchments as well as coastal areas. The resolution of the results is purely a function of the resolution of the input data, as the mathematical formulations are independent of scale. For example, gridded water levels from a model may be incorporated on any size grid.

The MDSF provides a ‘reference’ or ‘present day’ case and thereafter, any additional cases which include the user defined scenarios for change and/or combinations of measures are termed Case 2, Case 3, Case 4 etc. Each case is associated with a moment or ‘snapshot’ in time, and in order to build-up a dynamic picture, multiple cases can be evaluated over time. In addition, the input water levels are associated with discrete single events rather than the time-varying event hydrograph or moving towards continuous simulation. The duration of inundation is not considered.

Table 3: Review against criterion “Spatial and temporal scales” for MDSF.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Planning time horizon</th>
<th>Scenario time horizon</th>
<th>General time steps</th>
<th>Model time steps</th>
<th>Spatial scale</th>
<th>Spatial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDSF</td>
<td>any</td>
<td>any</td>
<td>any (evaluated discretely)</td>
<td>any (model independent)</td>
<td>any</td>
<td>any GIS supported files e.g. raster, shape</td>
</tr>
</tbody>
</table>

2.3 Methodology

2.3.1 Criterion “Input data”

For display of the flood risk areas, and subsequent linking of this information to the calculation of flood damages and social impacts, the MDSF uses (user input):
- Flood levels, generated externally, and/or
- Flood depths as a grid, generated externally, and/or
- Flood extents, generated externally (for example as calculated from earlier detailed studies, or from flood mapping)
- The delineation of defended areas which is user defined.

And the internal MDSF database includes:
- Background mapping (to aid the screen display)
- River centre lines
- National Property Database
- Social Flood Vulnerability Index
- Agricultural land-use classification
- Population data
- Administrative boundaries
- Existing flood maps
- Environmental sites
The MDSF is model independent.

Table 4: Review against criterion “Input data” for MDSF.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Availability</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>National DTM</td>
<td>Next Map</td>
<td></td>
<td>Not restricted</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local EA office</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River centre lines</td>
<td>EA (within MDSF)</td>
<td></td>
<td>Not restricted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>National Property Database</td>
<td>Local EA office</td>
<td></td>
<td>Not restricted</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Population data</td>
<td>EA (within MDSF)</td>
<td></td>
<td>Not restricted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Social Flood Vulnerability Index</td>
<td>EA (within MDSF)</td>
<td></td>
<td>Not restricted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Agricultural land-use classification</td>
<td>EA (within MDSF)</td>
<td></td>
<td>Not restricted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Administrative boundaries</td>
<td>EA (within MDSF)</td>
<td></td>
<td>Not restricted</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Erosion contours (for SMP)</td>
<td>EA</td>
<td></td>
<td>Not restricted</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Water levels, depth grid or flood extent</td>
<td>External models</td>
<td></td>
<td>Not restricted</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Criterion “Methods”

The MDSF is model independent. It uploads results or input data derived from external models i.e. ‘pre-processed’ data, which may be termed soft-coupling. For this, there is no restriction on the source model or information. There is no hard-coupling between the MDSF GIS Framework and any external models.

The MDSF methodology enables assessment of flood risk in terms of (i) economic damage to property and (ii) people, as it:

- incorporates 50 different water depth versus damage curves for a wide variety of residential and commercial properties based on extensive research carried out by the Flood Hazard Research Centre, Middlesex University;
- allows average annual economic damage to be estimated for individual properties and aggregated at any scale for which the user wishes to define a polygon;
- allows flood risk in terms of number of people potentially at risk from flooding to be calculated and average annual damage (AAD) to be calculated from an individual property level to a catchment level;
- includes a Social Flood Vulnerability Index based on socio-economic factors such as unemployment, overcrowding, the elderly, single parents. This allows the most vulnerable people in the floodplain to be identified; and
- it calculates agricultural damage.

2.3.3 Criterion “Uncertainty”

The MDSF includes a simple calculation allowing the user to define upper and lower pre-determined bounds on the input flood levels which is then translated to uncertainty in economic damage to commercial and residential, affected population and social vulnerability. The procedure allows for the bands to be set at any degree of confidence the user considers to be appropriate.
2.4 Presentation

2.4.1 Criterion “Target end-users”

The MDSF target end-users are the Environment Agency of England and Wales (EA); the EA consultants undertaking CFMPs and SMPs; and the Local Authorities.

Table 5: Review against criterion “Target end-users” for MDSF.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDSF</td>
<td>EA</td>
<td>Intermediate</td>
</tr>
<tr>
<td>MDSF</td>
<td>EA consultants</td>
<td>Good</td>
</tr>
<tr>
<td>MDSF</td>
<td>Local Authorities</td>
<td>Basic</td>
</tr>
</tbody>
</table>

2.4.2 Criterion “Visualisation”

The MDSF software tool comprises a customised open-architecture GIS tool, and thus all the results and information are presented in shape files, raster images and the corresponding attribute data is accessible in tabular form (e.g. Figure 1 & 2). This enables a useful visual interpretation to aid the decision maker, in particular, with respect to spatial planning and zoning.

Table 6: Review against criterion “Visualisation” for MDSF.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDSF</td>
<td>t, d, m</td>
<td>none</td>
</tr>
</tbody>
</table>

Figure 1: Example screen shot of the MDSF property damage calculation
2.5 Technological realisation

2.5.1 Criterion “Software architecture”

The MDSF software is a customised open-architecture GIS tool developed to work with ArcView Version 3.2a. There are no hard links to external models and the MDSF modelling. Data is readily added or removed from the system in a manner consistent with adding or removing layers in a GIS environment. It has an open framework meaning that water levels can be imported from any hydraulic model e.g. ISIS, HEC-RAS, TU-Flow, SOBEK etc.

Table 7: Review against criterion “Software architecture” for MDSF.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDSF</td>
<td>y</td>
<td>Any recognised by ArcView e.g. shapefile, raster, csv, txt etc.</td>
<td>n</td>
<td>ArcView V3.2a</td>
<td>y</td>
<td>VB &amp; ArcView Avenue script</td>
</tr>
</tbody>
</table>

2.6 Others

2.6.1 Criterion “Application”

The MDSF is widely used in the UK which can be attributed to:
- It **automates** a number of **tedious calculations** allowing economic damage for tens of thousands of properties.
- It includes **agricultural** calculations.
- **User Support** which includes general advice and support to users for the Procedures, Software and User Guide including hot-line support. The guidelines ensure the support is responded to within 24 hours and provided within 3 working days.
- **Software maintenance** which includes (i) monitoring the use of the MDSF; (ii) maintenance and servicing of the MDSF website; (iii) provision of the MDSF to users on a CD; (iv) user group meetings; (v) maintenance of the Procedures and...
Software including bug fixes to existing functionality; and (vi) preparation and distribution of upgrades to the Procedures and Software.

- **User Training**: this typically takes half a day and is provided on request.
- **Incorporated national data sets**: the base data sets are supplied and available with the software (on a CD), for example, the river network and social vulnerability indices. The DTM and National Property Database are not embedded due to the size, but are readily obtainable from the EA. Imported data sets can be used to improve on existing base data.
- **Advocated by the EA** for use by consultants in undertaking CFMPs and SMPs.

The MDSF has been applied outside of the UK, to an area in South East Asia, for the Mekong River Basin Commission (see: [http://www.mrcmekong.org/annual_report/ar5.htm](http://www.mrcmekong.org/annual_report/ar5.htm) and [http://www.halcrow.com/archivenews_march02_mekong.asp](http://www.halcrow.com/archivenews_march02_mekong.asp)). For this, the open code was updated to suit the local requirements, data and conditions.

2.6.2 Criterion “Weaknesses and strengths”

*The MDSF key strengths are that it:*
- is an open architecture GIS tool i.e. model independent;
- has no restrictions on spatial resolution of data;
- can be applied at any scale;
- is widely used throughout the UK, with available user support and training;
- provides a valuable system for establishing which assets or systems of assets are at risk;
- provides economic data regarding expected damage;
- includes a simple approach for uncertainty.

*The MDSF weaknesses are that it:*
- it requires proprietary software, ArcGIS, for which there are associated costs and licensing and some users may favour alternatives e.g. MapInfo;
- it does not consider performance of defences e.g. reliability and failure modes
- does not post-processing tools e.g. cost-benefit analyses, multi-criteria analyses, present values calculations etc.

MDSF2 is currently under development. The key objective of this is to incorporate risk-based methods (Section 6) into MDSF, incorporating defence reliability and failure modes. A further requirement is to ensure the engine is as software independent as possible i.e. limit the dependence on proprietary software such GIS or MapInfo.
3. DESIMA

3.1 Brief Description

Decision Support for Integrated Coastal Zone Management (DESIMA) is an information tool developed under a European Commission project in 1998 led by Matra Systems & Information from France, with partner contributions from Mecanique Appliquee et Sciences de l'Environnement (ACRI) in France, Satellite Observing Systems UK, and HR Wallingford UK. The project aim was to provide an information tool for decision makers to give efficient answers for the development of operational and integrated coastal zone management. The coastal zone experiences a variety of increasing and competing demands and a major challenge is to achieve a balance among the sometimes incompatible, activities such as tourism, fishing, hazard mitigation and marine research. The need was therefore identified for tool to assist decision-making, effective management, protection and development of the coastal zone.

3.2 Contents

3.2.1 Criterion “Flood risk system”

For this system, it is essential to distinguish between provision of an operating system which integrates data from different sources, passes the data through a series of modules and then demonstrates the results in a manner to assist decision makers from a DSS tool geared specifically towards solving particular long-term flood risk management planning issues. The DESIMA prototype tool was arbitrarily chosen to address certain coastal issues, however, the true measure of success was the enactment of the operating system, including the architecture, the data interfacing (from various information sources such as earth observation, in-situ data and numerical models) and the translation of this information into a useful decision making format.

If the DESIMA information tool were evaluated against the “food risk system” criteria, it may be noted that it does reflect elements of the source, pathway and receptor terms. For example, the external models may be altered to reflect changes in source loading and the pathways are represented through the data and methods (e.g. breach development). The results are viewed through a decision support information tab, which is analogous to the decision support module, where selected information and results are plotted or displayed visually.

3.2.2 Criterion “Measures and Instruments”

The DESIMA framework enables measures and instruments to be introduced into the system as appropriate. For the DESIMA prototype tool, measures were included through altering the input data or models, for example, altering topographic data or raising the sea-wall height. These were then incorporated as a series of design options, including the present day case. However, more specific, targeted measures could be included for other enactments of the system. A facility for multiple changes can be included in the operating system, enabling combinations of measures.

3.2.3 Criterion “Scenarios for external change”

The DESIMA framework is data driven and therefore the most basic method for considering scenarios for external change is to alter the source data i.e. alter the external model or loading conditions. For the DESIMA prototype, modules were generated to represent climate, namely present day, sea level rise and increased storminess.
3.2.4 Criterion “Spatial and temporal scales”
The spatial and temporal scale is unrestricted. The DESIMA prototype tool was developed for a specific coastal application, however, the DESIMA operating system is readily extendable to other applications. It is not restricted to flood risk management or even water related fields.

Table 8: Review against criterion “Spatial and temporal scales” for DESIMA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Planning time horizon</th>
<th>Scenario time horizon</th>
<th>General time steps</th>
<th>Model steps</th>
<th>Spatial scale</th>
<th>Spatial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIMA</td>
<td>Any</td>
<td>Any</td>
<td>Any</td>
<td></td>
<td>Any</td>
<td>Any</td>
</tr>
</tbody>
</table>

3.3 Methodology

3.3.1 Criterion “Input data”
The DESIMA operating system provides the scope to interface with the data sources, such that large data sets stay with data providers and the data formats do not have to be changed. This is a useful approach in the instance where the data is regularly being updated, for example, weekly or daily precipitation. The users have real-time access to data and models through a user interface that allows interpretation of various formats on a single PC or workstation using a regular browser. For the DESIMA prototype tool, typical data sets included bathymetry, wind and wave data, tidal levels, sea defence heights, joint probabilities and economics.

3.3.2 Criterion “Methods”
The methods within the DESIMA prototype tool were selected as appropriate to the pilot sites, to demonstrate enactment of the DESIMA framework. Examples of the modules used for the sea wall defence case study are:
- Predict offshore wave climate
- Predict near shore wave climate
- Establish extreme wave and water level conditions
- Analysis of in situ beach profile data
- Predict long term future beach behaviour
- Assess breach risk at a given locations
- Calculate flood maps for various return periods
- Evaluate economic appraisal

3.3.3 Criterion “Uncertainty”
DESIMA does not include an uncertainty module.

3.4 Presentation

3.4.1 Criterion “Target end-users”
The end users for the DESIMA prototype tool are authorities or consultants interested in the development of operational and integrated coastal zone management.

Table 9: Review against criterion “Target end-users” for DESIMA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIMA</td>
<td>Authorities</td>
<td>Basic</td>
</tr>
<tr>
<td>DESIMA</td>
<td>EA consultants</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>
3.4.2 Criterion “Visualisation”

The DESIMA prototype tool map-based user interface enables photographs and diagrams to be uploaded, results to be shown on graphs and viewing of maps to scale.

Table 10: Review against criterion “Visualisation” for DESIMA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIMA</td>
<td>t, d, m</td>
<td>none</td>
</tr>
</tbody>
</table>

3.5 Technological realisation

3.5.1 Criterion “Software architecture”

DESIMA has an open architecture which is distributed and interoperable. The prototype tool includes various data inputs, delivered by several data providers, and local and remote data sets and models, facilitating integration between these data and models. DESIMA provides real-time access to these data and models through a map based user interface that allows interpretation of various data formats on a single personal computer or workstation using a regular browser. The decision making process in coastal management involves a series of inter-related mathematical models to forecast coastal behaviour under different scenarios. This is streamlined in DESIMA, by cascading the models such that requesting a high-level decision automatically invokes the component models. For example, a request for seawall overtopping information automatically invokes the generation of offshore wave climates, offshore to inshore refraction processes and overtopping calculations.

Table 11: Review against criterion “Software architecture” for DESIMA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIMA</td>
<td>y</td>
<td>To external data sources</td>
<td>n</td>
<td>Map based interface</td>
<td>y</td>
<td>JavaScript</td>
</tr>
</tbody>
</table>

3.6 Others

3.6.1 Criterion “Application”

As part of the project, the DESIMA prototype tool was developed to enact the operating system framework. As mentioned above, this was designed to integrate information from sources such as satellite data, in situ measurements and numerical models to simulate events in two specific locations. HR Wallingford investigated the coastal defence issues around West Bay in Dorset, a region that illustrates many of the features common to all coastal management situations. ACRI simulated an oil spillage scenario in the Gulf of Lyon, where consideration was given to which data sets were needed, how these could be called up remotely from different providers across Europe and whether they could then be meshed together into a single real-time system for use by coastal engineers.

3.6.2 Criterion “Weaknesses and strengths”

In considering the strengths and weaknesses of the tool, it is important to consider the criteria for this. For example, the DESIMA prototype tool was purely developed as a means to enact a framework i.e. to illustrate the benefits of an operating system which can draw on various data sources, process the data through the relevant calculations, and then present the results in a format that aids the decision making process. In other words, the methods themselves are fairly arbitrarily chosen, and in this instance they were for a coastal application.
The key strengths of the DESIMA operating system framework are that it:
- provides an efficient distributed and interoperable open architecture which does not rely on proprietary software;
- interfaces with data and models in real time, thus avoiding issues such as data upgrades, licensing and enabling real time forecasting and evacuation planning as well as scope for long-term planning;
- it is not restricted by temporal or spatial scales;
- it has the flexibility to include any appropriate modules or methods;
- benefits end-users who will profit from a DESIMA information system through more efficient decision making leading to cost and time savings and assuring a sustainable development of natural resources in coastal zones;
- enables end-users to economize their investments in human and non-human resources to the necessary functional dimension because the DESIMA distributed architecture avoids that know-how and informatics equipment are unnecessarily duplicated at the user's site.

The weaknesses of the DESIMA operating system framework are that it:
- for some applications, it may be more beneficial to have the data stored locally, such that the data and methods may be more intricately linked;
- there is no existing training, user support or software maintenance;
- the existing prototype tools and methods are specific to coastal applications.
4. **FloodRanger**

4.1 **Brief Description**

FloodRanger is an educational game about managing flood defences along rivers and coasts, but is included here as it incorporates some of the concepts peculiar to long-term planning, such as future population or climate change scenarios. The tool is intended to raise awareness of flood and coastal defence issues in a way that is both fun and thought-provoking. The game uses a virtual terrain loosely based on the east coast of England and the objective is to defend urban areas and sites of special scientific interest while maintaining levels of housing and employment for an expanding population. The development of FloodRanger was funded by the Office of Science and Technology in the UK as part of the Foresight programme. It is a joint project between Discovery Software Ltd. and View the World Ltd.

4.2 **Contents**

4.2.1 **Criterion “Flood risk system”**

FloodRanger incorporates source, pathway and receptor terms. The volume of water entering the catchment is calculated based on rainfall runoff; permeability of the underlying geology; the drainage network; rainstorm events of different sizes and frequency; tidal height; sea level rise; coastal subsidence and storm surges. The receptor terms are represented through the floodplain land use, for example, housing, industry development, cities, forests, Sites of Special Scientific Interest (SSSIs) and National Parks.

4.2.2 **Criterion “Measures and Instruments”**

The management measures include sea defences and river defences. There are four types of sea defences including: beach replenishment, groynes, saltmarshes and sea walls and there are seven types of river defences including: small and large weirs, locks, dykes, river walls, demountables and reservoirs. There is also a tidal barrier, which is a special case, classified within river defences but also providing defence against coastal flooding events.

4.2.3 **Criterion “Scenarios for external change”**

The user can select between two world future scenarios in combination with four climate change scenarios taken from the UK Hadley Centre for Climate Change.

The future climate description is based on the four different emissions scenarios published by the Intergovernmental Panel on Climate Change [www.ipcc.ch] and used in the UK Climate Impacts Programme (UKCIP02). The four climate change scenarios (Low, Medium-Low, Medium-high and High) are based on the Hadley Centre climate model plus higher resolution regional models to simulate changes over a grid with a 50 km resolution.

Two world futures scenarios have been built into Flood Ranger: World Markets and Local Stewardship. They are derived from the UK national Foresight Programme (OST, 2004). World scenarios form a starting point for major trends and influences that will have an impact on markets, society and the environment. The context of these scenarios comes from looking at the spectrum of development in governance between globalisation and regionalisation and social values from consumerism and community. The main characteristics of the two scenarios are shown in Table 12.
Table 12: Main scenario characteristics (OST, 2004)

<table>
<thead>
<tr>
<th></th>
<th>World Markets</th>
<th>Local Stewardship</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Values</strong></td>
<td>Consumerist</td>
<td>Conservative</td>
</tr>
<tr>
<td><strong>Governance</strong></td>
<td>Globalised</td>
<td>Regional/National</td>
</tr>
<tr>
<td><strong>GDP</strong></td>
<td>3% per year</td>
<td>1% per year</td>
</tr>
<tr>
<td><strong>Fast growing sectors</strong></td>
<td>health care, leisure, distribution, financial services</td>
<td>small-scale, intensive manufacturing, locally based financial and other services, small-scale agriculture</td>
</tr>
<tr>
<td><strong>Declining sectors</strong></td>
<td>manufacturing, agriculture</td>
<td>retailing, leisure, tourism</td>
</tr>
<tr>
<td><strong>Index of Sustainable Economic Welfare</strong></td>
<td>-2%</td>
<td>+1%</td>
</tr>
<tr>
<td><strong>Environmental State – air quality</strong></td>
<td>general decline</td>
<td>mixed</td>
</tr>
<tr>
<td><strong>Environmental State – water quality</strong></td>
<td>mixed</td>
<td>general improvement</td>
</tr>
<tr>
<td><strong>Environmental State – biodiversity</strong></td>
<td>under pressure</td>
<td>improves</td>
</tr>
<tr>
<td><strong>Environmental State – climate</strong></td>
<td>emissions trading</td>
<td>weak management</td>
</tr>
</tbody>
</table>

4.2.4 **Criterion “Spatial and temporal scale”**

The virtual digital terrain model has a grid resolution of 250 m and is based on an area on the east coast of England. The user is charged with managing the flood risk over a period of 100 years, while maintaining housing and employment levels for an expanding population.

Table 13: Review against criterion “Spatial and temporal scales” for FloodRanger.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Planning time horizon</th>
<th>Scenario time horizon</th>
<th>General time steps</th>
<th>Model time steps</th>
<th>Spatial scale</th>
<th>Spatial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>FloodRanger</td>
<td>100 year</td>
<td>100 year</td>
<td>10 year</td>
<td></td>
<td>3D visualisation</td>
<td></td>
</tr>
</tbody>
</table>

4.3 **Methodology**

4.3.1 **Criterion “Input data”**

The FloodRanger ‘data’ is embedded within the game.

4.3.2 **Criterion “Methods”**

The region has been created using an extensive hydrological model built into a 3D landscape, which takes into account real information about rainfall, drainage, tides, climate and topography. The game is a stand alone piece of software that does not interface with alternative data sources or models i.e. no hard- or soft-coupling.
The FloodRanger assessment provides results based on independent assessments of particular issues rather than a multi-criteria type analysis. For example, typical results include “% areas at risk of flooding”, “% health of environment” or “% regional insurance premium”.

### 4.3.3 Criterion “Uncertainty”

FloodRanger does not explicitly consider uncertainty.

### 4.4 Presentation

#### 4.4.1 Criterion “Target end-users”

The target audience are flood defence practitioners, local authorities, insurers, universities and schools. The “target” end users require limited background knowledge as the game is explained at a very basic level.

Table 14: Review against criterion “Target end-users” for FloodRanger.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>FloodRanger</td>
<td>Flood defence practitioners</td>
<td>Basic</td>
</tr>
<tr>
<td>FloodRanger</td>
<td>Local authorities</td>
<td>Basic</td>
</tr>
<tr>
<td>FloodRanger</td>
<td>Insurers</td>
<td>Basic</td>
</tr>
<tr>
<td>FloodRanger</td>
<td>Universities &amp; schools</td>
<td>Basic</td>
</tr>
</tbody>
</table>

#### 4.4.2 Criterion “Visualisation”

FloodRanger enables 3D visualisations and animations. Layers containing information about different features, for example, moors, grasslands and substrate type are displayed through overlays.

Table 15: Review against criterion “Visualisation” for FloodRanger.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>FloodRanger</td>
<td>t, d, s</td>
<td>s</td>
</tr>
</tbody>
</table>

Figure 3: Screen shot of FloodRanger (Courtesy of Discovery Software).
4.5 Technological realisation

4.5.1 Criterion “Software architecture”

FloodRanger is a closed architecture as it is a stand-alone software.

Table 16: Review against criterion “Software architecture” for FloodRanger.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>FloodRanger</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td></td>
<td>n</td>
<td></td>
</tr>
</tbody>
</table>

4.6 Others

4.6.1 Criterion “Application”

The FloodRanger game is available via the Internet for a nominal fee at http://www.discoverysoftware.co.uk/FloodRangerBuy.htm. More than 40 copies have been sold to the United States Environmental Protection Agency and the Thames Barrier has inquired after its own custom-made version.

A promotional workshop was held on the 17 February 2004. This included attendees from consultancies and government agencies from England and Wales, Germany, the Netherlands and Belgium. The findings were that “Delegates were generally very impressed with FloodRanger and many expressed an interest in obtaining a copy. It was felt that this type of model could be good for public education, but FloodRanger itself is rather complex, and many of the concepts and measures would not be understood by the non-specialist. It helped delegates get a feel for strategic planning of a whole catchment or coastal area. Overall, delegates were impressed with the features, but some suggestions were made for improvements. The software was reasonably easy to use.”

4.6.2 Criterion “Weaknesses and strengths”

The key strengths of FloodRanger are that it:
- serves as a valuable educational tool for communicating the issues associated with long-term flood management
- is easily accessible via the Internet
- does not require proprietary software
- provides useful 3D visualisations of the flood system

The weaknesses of FloodRanger are that:
- some of the long-term planning issues are not easily understood by non-specialists
- it does not introduce uncertainty concepts
- it is a game and therefore cannot be used for Flood Risk Management
- it does not allow for flooding
5. **EUROTAS**

5.1 **Brief Description**

The EUropean River Flood Occurrence & Total Risk Assessment System (EUROTAS) was funded by the European Commission from the 2nd call of the Fourth Framework under the Hydrological Risk component of the Environment and Climate Programme. The EUROTAS Decision Support System provides a framework to assist planners and decision makers in undertaking catchment studies whilst fulfilling a range of objectives. These include undertaking river management studies in a “quality assured” manner through some form of information management system; ensuring the decisions made and their predicted consequences are recorded and that the benefits and drawbacks can be demonstrated to the relevant stakeholders and political decision makers. The EUROTAS Project was led by HR Wallingford with contributions from the Danish Hydraulic Institute (Denmark), Delft Hydraulics and the Institute of Inland Water Management and Waste Water Treatment (Netherlands).

5.2 **Contents**

5.2.1 **Criterion “Flood risk system”**

The EUROTAS DSS incorporates the various source, pathway and receptor components of the flood risk system. Water levels are obtained from external models. Pathways are represented through cross-sections and Digital Terrain Model information and the DSS includes a flood spreading algorithm for the imported water levels. The receptor information is represented as a vulnerability layer (or shape file), providing the potential consequences at a given location. This distinguishes between urban areas, non-critical areas such as forests and grassland and it considers agriculture land-use and farm management practices. The vulnerability layer defines the size of the event at which inundation is acceptable for each location given its land-use.

The DSS includes a management / decision support type module, whereby the user can construct queries and search the catchment simulations for conditions which match a certain set of objectives or “goals”. The DSS applies case-based reasoning to explore the database of model simulations to identify which ones best satisfy the flood risk management objectives.

5.2.2 **Criterion “Measures and Instruments”**

The types of measures include “river engineering scenarios” which include, for example, construction of diversion channels, channel enlargement, embankment, hydraulic control structures, lowering ground levels on flood plains etc (Table 16). Three distinct phases are considered: (i) pre-feasibility planning phase, (ii) feasibility phase and (iii) the detailed design stage. The level of modelling and detail is appropriate to the phase i.e. (i) 1D models, (ii) detailed 1D model adopting a multi-disciplinary approach which covers a large part of the river system and (iii) detailed 2D/3D models respectively. The pathway and receptor measures also include the facility for altering the land-use, which include urban areas, open water, types of agricultural use, grassland, forest and upland.
Table 17: Example of EUROTAS DSS river engineering measures.

<table>
<thead>
<tr>
<th>Measure Name</th>
<th>Category</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floodplain Lower</td>
<td>Floodplain</td>
<td>Lower floodplain by following the current contours</td>
</tr>
<tr>
<td>Floodplain Level</td>
<td>Floodplain</td>
<td>Lower floodplain to a given level</td>
</tr>
<tr>
<td>Roughness</td>
<td>Floodplain</td>
<td>Change roughness of the floodplain by changing vegetation or maintenance regime</td>
</tr>
<tr>
<td>Add Embankment</td>
<td>Floodplain</td>
<td>Add an embankment in the floodplain</td>
</tr>
<tr>
<td>Widem Model Boundary</td>
<td>Floodplain</td>
<td>Widem the model boundary (this measure often taken in combination with floodplain lowering. The model boundary determines the extent of the cross sections)</td>
</tr>
<tr>
<td>Edit Embankment</td>
<td>Floodplain</td>
<td>Change an existing embankment</td>
</tr>
<tr>
<td>Edit Flow/Storage division</td>
<td>Floodplain</td>
<td>Change the division between flow storage and conveyance sections (for example by removing obstacles perpendicular to the flow direction such as roads cross the floodplain)</td>
</tr>
<tr>
<td>Lower Main Channel</td>
<td>Main Channel</td>
<td>Lower the main channel by dredging, for navigation, desilting or regrading of the bed</td>
</tr>
<tr>
<td>Widem Main Channel</td>
<td>Main Channel</td>
<td>Widem the main channel. This measure will also involve changing the main channel banks. Although these are typically not physical entities they are used in the cross section generation routine</td>
</tr>
<tr>
<td>Structure Set Point</td>
<td>Rule Curves</td>
<td>Change the operation of a weir, particularly during high flows.</td>
</tr>
<tr>
<td>Hydropower Discharge</td>
<td>Rule Curves</td>
<td>Change the discharge through hydropower stations.</td>
</tr>
<tr>
<td>Lateral Discharges</td>
<td>Rule Curves</td>
<td>Change lateral inflow discharges. This measure is closely related to changes in the catchment through land use changes, but allows more flexibility</td>
</tr>
<tr>
<td>Storage Operation</td>
<td>Rule Curves</td>
<td>Change rule curves for the use of possible off-line retention basins</td>
</tr>
</tbody>
</table>

5.2.3 Criterion “Scenarios for external change”

The EUROTAS DSS includes scope for external drivers such as climate change. The external climate change model incorporates an Expanded Downscaling (EDS) method which generates point rainfall and other appropriate meteorological time series data for future climate change scenarios based upon historic data at the site and scenario predictions from a General Circulation Model (GCM).

The project recommended development of a real climate change procedure which incorporates more readily and flexibly the climate information from global climate models and transfers it into weather information. The core element would be a weather generator with climate dependent parameters.

5.2.4 Criterion “Spatial and temporal scales”

The EUROTAS DSS is designed for catchment scale applications.

Table 18: Review against criterion “Spatial and temporal scales” for EUROTAS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Planning time horizon</th>
<th>Scenario time horizon</th>
<th>General time steps</th>
<th>Model time steps</th>
<th>Spatial scale</th>
<th>Spatial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUROTAS</td>
<td>10-100year</td>
<td>100year</td>
<td></td>
<td></td>
<td>Catchment scale</td>
<td>Shape files, DTM, raster</td>
</tr>
</tbody>
</table>
5.3 Methodology

5.3.1 Criterion “Input data”

The input data is summarised in Table 19 below.

Table 19: Review against criterion “Input data” for EUROTAS.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Availability</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTM</td>
<td>National DTM</td>
<td></td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River cross-sections</td>
<td>User / other Shapefiles, .txt files</td>
<td></td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic structure information</td>
<td>User / other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water levels</td>
<td>Imported from models</td>
<td></td>
<td>Any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Cover Map</td>
<td>Embedded in DSS but potential to add new information</td>
<td>0.5km pixel resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3.2 Criterion “Methods”

The DSS tool allows the user of the system to construct queries (Figure 4) and search the catchment simulations for conditions which match a certain set of objectives or “goals”. The DSS applies case-based reasoning to explore the database of model simulations to identify which ones best satisfy the flood risk management objectives. The cases are described through descriptions of the climate change, land-use and river engineering scenarios. These are then exported to external hydraulic and hydrologic simulation models (e.g. ISIS, SOBEK, CLASSIC) and post-simulation, the results are re-imported to the DSS for analysis. Analysis includes, for example, consideration of water levels and environmental impacts to identify the most appropriate solution.

The methods are based on a rules-based “goal” driven approach, where the user defines the objectives and the various options are evaluated on a case-based reasoning to identify which option best satisfies the flood risk management objectives.
5.3.3 Criterion “Uncertainty”

Uncertainty approach adopted in the EUROTA S project is based on the General Likelihood Uncertainty Estimate (GLUE) methodology. The GLUE procedure provides tools for sensitivity analysis and uncertainty estimation using the results of Monte Carlo simulations. Here, it was used to determine the uncertainty of the design flood, the flood simulation and to propagate the uncertainty through to the inundation area.

5.4 Presentation

5.4.1 Criterion “Target end-users”

The DSS prototype was intended to assist planners, decision makers, local authorities and Agencies involved in flood risk management.

Table 20: Review against criterion “Target end-users” for EUROTAS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUROTAS</td>
<td>Planners (land-use)</td>
<td>Intermediate</td>
</tr>
<tr>
<td>EUROTAS</td>
<td>Decision makers</td>
<td>Intermediate</td>
</tr>
<tr>
<td>EUROTAS</td>
<td>Public authorities</td>
<td>Basic</td>
</tr>
<tr>
<td>EUROTAS</td>
<td>Agencies involved in flood defence provision</td>
<td>Intermediate</td>
</tr>
<tr>
<td>EUROTAS</td>
<td>Educational institutes</td>
<td>Basic</td>
</tr>
<tr>
<td>EUROTAS</td>
<td>Academic researchers</td>
<td>Expert</td>
</tr>
</tbody>
</table>

5.4.2 Criterion “Visualisation”

Visualisation includes static maps, shape files and raster images i.e. all file types typically associated with an ArcGIS environment (Figure 5).

Table 21: Review against criterion “Visualisation” for EUROTAS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUROTAS</td>
<td>t, d, m</td>
<td></td>
</tr>
</tbody>
</table>
5.5 Technological Realisation

5.5.1 Criterion “Software architecture”

The EUROTAS DSS is based around the ArcView GIS software package and it is fully integrated within the overall Integrated Catchment Modelling (ICM) framework.

Table 22: Review against criterion “Software architecture” for EUROTAS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUROTAS</td>
<td></td>
<td></td>
<td>yes</td>
<td>ArcView GIS</td>
<td></td>
<td>Avenue (main) VB, C++, Fortran (elements)</td>
</tr>
</tbody>
</table>

The DSS tool includes coupling with commercial hydraulic and hydrological models, for example, the ISIS, MIKE11 and SOBEK hydrodynamic modelling suites and the CLASSIC, DCN and HBV catchment hydrological models. The ICM links existing models together using data exchange protocols around agreed formats, coupling the process models at a “coarse grained” level of interaction. These protocols and formats are a key output of the EUROTAS project.

5.6 Others

5.6.1 Criterion “Application”

Prototype DSS tools were built to enact the EUROTAS framework. These were applied to five pilot sites: the SAAR Rhine (Netherlands), the Thames (UK), the Pinios (Greece), the Elbe (Germany) and Liri-Garigliano (Italy). The issues considered included river engineering, land-use change, climate change, risk and uncertainty (Table 23).
Table 23: Pilot catchments and issues considered in each pilot site.

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area (km²)</th>
<th>Issues Considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saar</td>
<td>7,400</td>
<td>River engineering, land use change, and climate change</td>
</tr>
<tr>
<td>Thames</td>
<td>10,000</td>
<td>River engineering, land-use change, and climate change</td>
</tr>
<tr>
<td>Pirios</td>
<td>4,000</td>
<td>Land-use change and Climate Change</td>
</tr>
<tr>
<td>Elbe</td>
<td>150,000</td>
<td>Land-use change, Climate change</td>
</tr>
<tr>
<td>Liri-Garigliano</td>
<td>5,000</td>
<td>Risk and Uncertainty</td>
</tr>
</tbody>
</table>

The DSS tool was project specific and therefore not intended for commercial distribution. Despite this, dissemination of the knowledge and project demonstration CD has taken place. This has been through conferences e.g. (i) Advances in Flood Research and (ii) Hydrology and Earth Systems Science, as well as knowledge feeding into the 5th Framework EC project Mitigation of Climate Induced Hazards (MITCH) and initiatives such as EU-MEDIN for the mitigation of flash flood risks. Any commercial DSS would need further development from the prototype, possibly with additional proprietary software tools.

5.6.2 Criterion “Weaknesses and strengths”

The key strengths of the EUROTAS DSS are that it:
- incorporates the components of the flood risk system i.e. Source, Pathway, Receptor;
- includes a reasonably good climate change model albeit a static component;
- incorporates environmental impacts;
- incorporates uncertainty modelling using Monte Carlo analysis within the GLUE approach;
- has been applied to five pilot sites located in different countries, illustrating ease of application for different countries and with varying data sets / models.

The weaknesses of the EUROTAS DSS are that it:
- has direct coupling with models. While this is an achievement in terms of the software integration i.e. models passing information to one-another, it limits the use with alternative models.
- to provide a commercial product (which it was not originally intended for), it would require further development from the prototype
- is no-longer in use as it was built to demonstrate/enact the methodologies within the project but was never intended for ongoing use.

For further information on EUROTAS, see
http://www.hrwallingford.co.uk/projects/EUROTAS/index.html
6. RASP Based DSS Tools

Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) is a framework which provides tools for risk assessment and decision support, with due consideration of sources of risk, risk pathways and receptors at risk. The RASP methodology is based on a probabilistic approach to determining the flood probability that can then be used to established expected annual damage for a range of impacts (e.g. £, people etc). Unlike all other approaches it explicitly recognises that sources, pathways and receptors behave as integrated systems and that flooding at a given location in the floodplain is a function of the performance of that system (including a range of storm events and possible defence responses and receptor behaviour). Key to the RASP analysis is the notion of hierarchy, which allowing data and models to be improved and uncertainty reduced within a common framework (Table 24, Figure 6 and 7).

Table 24: Hierarchy of RASP methodologies, decision support and data required.

<table>
<thead>
<tr>
<th>Level of assessment</th>
<th>Decisions to inform</th>
<th>Data sources</th>
<th>methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>National assessment of economic risk, risk to life of environmental risk</td>
<td>Defence type</td>
<td>Generic probabilities of defence failure based on condition assessment and SOP</td>
</tr>
<tr>
<td></td>
<td>Initial prioritisation of expenditure across all functions</td>
<td>Condition grades</td>
<td>Assumed dependency between defence sections</td>
</tr>
<tr>
<td></td>
<td>Regional Planning</td>
<td>Standard of Service</td>
<td>Empirical methods to determine likely flood extent</td>
</tr>
<tr>
<td></td>
<td>Flood Warning Planning</td>
<td>Indicative flood plain maps</td>
<td></td>
</tr>
<tr>
<td>High Level Plus</td>
<td>As above</td>
<td>Socio-economic data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land use mapping</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>Above plus: Flood defence strategy planning</td>
<td>Above plus: Digital Terrain Maps</td>
<td>Probabilities of defence failure from reliability analysis</td>
</tr>
<tr>
<td></td>
<td>Regulation of development</td>
<td>Quantitative loading</td>
<td>Systems reliability analysis using joint loading conditions</td>
</tr>
<tr>
<td></td>
<td>Regional prioritisation of expenditure across all functions</td>
<td>Floodplain depths in the absence of defences</td>
<td>Modelling of limited number of inundation scenarios</td>
</tr>
<tr>
<td></td>
<td>Planning of flood warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detailed</td>
<td>Above plus: Scheme appraisal and optimisation</td>
<td>Above plus: All parameters required describing defence strength</td>
<td>Simulation-based reliability analysis of system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detailed socio-economic data</td>
<td>Simulation modelling of inundation</td>
</tr>
</tbody>
</table>

Note: these levels of assessment do not uniquely support a single decision but rather elements of each can be used in combination.
Figure 6: Example of RASP High, Intermediate and Detailed Level Analysis.

Figure 7: Source/Pathway/Receptor/Consequence model for flood risk.

At present RASP supported DSS have either been developed or are in the process of being developed. These are outlined in the figure below.
Figure 8 Integrated planning decisions supporting Flood Risk Management

Only one of these tools, NaFRA has been developed to the stage of a DSS and PAMS is currently being developed. These are discussed below.

### 6.1 NaFRA

#### 6.1.1 Brief Description

The National Flood Risk Assessment (NaFRA) DSS tool, commissioned by the Environment Agency of England and Wales, has been developed by HR Wallingford with support of John Chatterton and Associates and Halcrow to support national planning policy in the UK. It is specifically designed for national application and enacts the so-called RASP High Level Methodology that forms part of a consistant hierarchy of risk assessment methods developed by HR Wallingford with support of the University of Bristol for the Environment Agency (RASP - Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) methodology [http://www.rasp-project.net/](http://www.rasp-project.net/)). This DSS has been used to support Foresight and a series of national flood risk assessments since 2000.

The NaFRA DSS tool is a national application of the High Level Method, which provides consistent information to support flood management policy, strategic prioritisation of investment in defence improvements or other flood management options and monitoring the performance of flood risk mitigation activities.

Note: Although the NaFRA DSS tool is fully-coded and functional, it is not a commercial software tool with a specifically designed User Interface. However, it has been used for the national applications in 2002, 2004 and 2005 and NaFRA 2006 is now underway. Each national application provides an improvement on the previous application, in that the methods and data sets are constantly evolving.

#### 6.2 Contents

##### 6.2.1 Criterion “Flood risk system”

The NaFRA DSS tool incorporates the RASP system-based analysis which considers the source, pathway and receptor terms. The source terms include the loading, for example, in-channel river water levels and coastal surge and wave conditions. The pathway terms include flood defences and the floodplain which may exist between the in-channel river flows and a housing development. The main considerations are therefore defence performance under load,
overtopping and floodplain inundation. The receptor terms cover any entity that may be harmed by a flood and the material damage that may be suffered where a quantitative relationship between flood depth (velocity is currently excluded at the national level) and the magnitude of the damage exists. The Receptor terms include information on exposure (e.g. property locations), quantified vulnerability (e.g. depth-damage curves) and agricultural production.

6.2.2 Criterion “Measures and Instruments”
The management measures in the NaFRA DSS tool are represented through altering the input data sets, for example, changing the crest level on a system of defences, altering the position or standard of protection of the defences or changing the floodplain land-use. ArcGIS based tools are available to assist in implementing these data changes.

6.2.3 Criterion “Scenarios for external change”
The scenarios for external change such as climate change are altered by changing the flow conditions and flow structures (e.g. introduction of in-line / off-line storage) in the off-line external models i.e. by altering the input loading conditions.

6.2.4 Criterion “Spatial and temporal scales”
The NaFRA DSS tool is independent of spatial or temporal scale. However, the methodological assumptions are consistent with the degree of uncertainty that can be tolerated at a policy level but would (typically) need to be reduced at action level.

Table 25: Review against criterion “Spatial and temporal scales” for NaFRA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Planning time horizon</th>
<th>Scenario time horizon</th>
<th>General time steps</th>
<th>Model time steps</th>
<th>Spatial scale</th>
<th>Spatial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaFRA</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
<td>Any</td>
<td>Shape files, DTM, raster images, individual defence data</td>
</tr>
</tbody>
</table>

6.3 Methodology

6.3.1 Criterion “Input data”

Table 26: Review against criterion “Input data” for NaFRA.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Availability</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>National DTM</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defence type</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition grades</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard of Service</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indicative floodplain maps</td>
<td>External model</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floodplain depths in the absence of defences</td>
<td>External model</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Socio-economic data</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land-use mapping</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valley type classification</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River centreline</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3.2 Criterion “Methods”

The methodology is based on a probabilistic approach to determining the flood risk and expected annual damage (£, people etc) at a given location in the floodplain as a result of the performance of the system of defences and the floodplain vulnerability. The method steps are to (i) generate flood extents for each defence, (ii) calculate defence systems for each impact zone, (iii) generate a series of depths for each impact zone and (iv) generate depths and probability for each combination of defence failure and return period. Issues considered include:

- High level – expert judgement and simplified modelled probabilities of defence failures given load based on condition assessment and Standard of Protection (SOP).
- Assumed dependency load between defence sections
- Assumed independence between defence sections in terms probability of failure
- Empirical methods to determine likely flood extent.

Within the RASP methodology, the flood spreading model dictates the reliability of the flooding parameters. In the NaFRA DSS tool, a simple parametric model is used due to the scale of the application. The limitation is that it cannot determine the velocity terms.

6.3.3 Criterion “Uncertainty”

The NaFRA methodology adopts an interval probability approach to describing uncertainty that considers and propagates uncertainty based on upper and lower bands which are applied to the defence fragility curves i.e. the loading versus the probability of failure and, receptor terms. These upper and lower cases are then propagated through the model to provide a final upper and lower case for each output, for example, Annual Exceedance Probability in Figure 9.

![Figure 9: Typical results from a NaFRA analysis showing flood depth versus probability relationship, integrating uncertainty by plotting upper and lower bounds.](image)

6.4 Presentation

6.4.1 Criterion “Target end-users”

The NaFRA DSS tool provides output information for:

- National assessment of economic risk, risk to life and risk to the environment
- Initial prioritisation of expenditure across all functions
- Regional planning
- Flood Warning Planning
Table 27: Review against criterion “Target end-users” for NaFRA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaFRA</td>
<td>EA* Strategic Planners</td>
<td>Medium - Basic</td>
</tr>
<tr>
<td>NaFRA</td>
<td>EA Regional and Area flood risk management teams</td>
<td>Medium - Basic</td>
</tr>
<tr>
<td>NaFRA</td>
<td>Local Authorities</td>
<td>Basic</td>
</tr>
<tr>
<td>NaFRA</td>
<td>EA Flood Warning team</td>
<td>Medium - Basic</td>
</tr>
</tbody>
</table>

*EA = Environment Agency

6.4.2 Criterion “Visualisation”

The decision support information is provided such as people risk, expected annual damages and environmental impacts. These are spatially differentiated and available at each time.

Table 28: Review against criterion “Visualisation” for NaFRA.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaFRA</td>
<td>t, m, d</td>
<td></td>
</tr>
</tbody>
</table>

6.5 Technological Realisation

6.5.1 Criterion “Software architecture”

Two databases are held in SQL Server. The Catchment Database contains the raw data that is required to do the processing, as well as the results of each of the processing stages. The Task Database contains the list of processing tasks that are to be carried out for one processing stage. The processing methodology has been divided into three steps:

- Flood extents
- Defence systems
- Flood depths

each of which is dependent on the results of the previous step.

**Distributed RASP HLM+ Processing – System Summary**

![Diagram](image)

*Figure 11: Existing RASP HLM+ architecture.*

**Table 29: Review against criterion “Software architecture” for NaFRA.**

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaFRA</td>
<td>y</td>
<td>n</td>
<td>ArcGIS</td>
<td>y</td>
<td>Data-preparation Visual Basic; NaFRA analysis tool is C# operating on an SQL database</td>
<td></td>
</tr>
</tbody>
</table>

**6.6 Others**

**6.6.1 Criterion “Application”**

The NaFRA DSS tool has been used for NaFRA 2002, 2004 and 2005 and NaFRA 2006 is now underway. Each of these national applications was to assess the present day case and each successive application provides an improvement in that the methods and data sets are constantly evolving. The analyses were undertaken by HR Wallingford and Halcrow, as the current software tool does not have a commercial front end for more general use. The results are then made available to the target end users (5.5.1) to assist decision making.

In parallel, the NaFRA 2002 data sets were used within the Foresight project to enact future scenarios, for example, with climate and demographic change. These results were used to inform the FloodRanger DSS tool / educational game (Section 4).

The NaFRA DSS tool is currently being applied within a UK national project, Thames Estuary 2100, which considers the flood risk management of the Thames Estuary for four epochs, including the year 2100.
6.6.2 Criterion “Weaknesses and strengths”

The key strengths of the NaFRA tool are that it:
- incorporates the flood risk system i.e. Source, Pathway and Receptor modelling;
- includes the latest climate change approach as described in the Foresight Project;
- it considers the reliability and failure modes of defences;
- incorporates some representation of uncertainty modelling, although it is based on a single parameter, the fragility curve, which is then propagated through the model;
- it has been applied nationally for the present day case and for two epochs under the Foresight project and is being used for the Thames Estuary 2100 project;
- provides a valuable system for establishing which assets or systems of assets are at risk;
- provides economic data regarding expected damage.

The weaknesses of the NaFRA tool are that it:
- provides a probabilistic predictions – these have inherent difficulties associated with understanding and for validation;
- to provide a commercial product will require further development from the current tool set and this will require a substantial work effort to simplify the input options for a ‘basic’ or intermediate’ level user.
7. **PAMS**

7.1 **Brief Description**

The Performance-based Asset Management System (PAMS) is a tool which enables flood and defence managers to assess the performance of, and management requirements for, existing flood defence assets. These may involve maintenance, adoption / replacement or removal. The long-term planning functionality provides a means of identifying the preferred management intervention to achieve a particular performance outcome or expenditure profile.

The PAMS DSS tool is included here, although it is still under development, due for completion in June 2008. To clarify, the conceptual methodologies which underpin the PAMS DSS are at an advanced stage of development and many of the DSS modules have been finalised, however the final front end and interfacing between the modules is still under development.

7.2 **Contents**

7.2.1 **Criterion “Flood risk system”**

The PAMS DSS includes source, pathway, receptor and consequence modules as well as a management intervention and decision support module. It is based on a probabilistic approach to determining the flood risk and expected annual damage (£, people etc) at a given location in the floodplain as a result of the performance of the system of defences and the floodplain vulnerability. The probabilistic approach is based on the Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) methodology (http://www.rasp-project.net/). The PAMS tool specifically focuses on the assets or system of assets, providing information on whether a given asset or asset property increases or decreases the flood risk. Application is unrestricted i.e. it can be applied to coastal, fluvial and estuary sites.

The source terms include base meteorological data, surge and river levels and wave heights imported from external models. The pathways include the asset description, for example crest and toe levels, breach information and the Digital Terrain Model. Information on condition grade, standard of protection and type of defence is also included as the PAMS DSS considers the time-dependent deterioration of due to hydraulic loads (e.g. toe scour) and non-hydraulic loads (e.g. animal burrowing). The reliability of assets is also included, for example crest erosion, rotational slip etc. The Receptor terms include information on exposure (e.g. property locations) and quantified vulnerability (e.g. depth-damage curves).

7.2.2 **Criterion “Measures and Instruments”**

The management measures or interventions to reduce the probability of flood inundation include modification to the system of hydraulics, for example, offline storage, barriers, breakwaters and land-use management changes and modification to existing asset performance, for example, increased maintenance and new build. Non-structural measures include the facility to alter the exposure and vulnerability hence increase resilience e.g. property zoning, evacuation planning, education etc.

7.2.3 **Criterion “Scenarios for external change”**

The module for future scenarios is still under development. Asset management takes place in the context of a changing world. The PAMS tool will be sufficiently flexible and adaptable to allow for changes in, for example:

- Treasury guidance (discount rates, appraisal periods, etc.)
- Government policy (sustainability, welfare, safety, environment, etc.)
- Climate change (sea levels, rainfall, river flows, etc.)
- Environmental requirements (e.g. soft engineering, habitats etc)
- Technology (updates in GIS, other databases, new methods of flood defence, etc.)
- Land use (construction of or removal of developments in areas at risk from flooding, use of fallow land for agriculture, etc.)

For this reason, the system is designed with an open architecture, allowing individual modules to be revised independently, to enable the input of appropriate information about such issues whether directly or indirectly. For the future scenarios, knowledge from the FORESIGHT programme on broader sustainability issues such as resilience, robustness and social justice will be considered.

7.2.4 Criterion “Spatial and temporal scales”

The spatial and temporal scale is unrestricted. The analysis can be applied at a national or local level and to fluvial or coastal locations. It is based on assessment of the risk in impact zones defined within the natural floodplain, the size of which can be defined as appropriate to the data resolution and computational load.

Table 30: Review against criterion “Spatial and temporal scales” for PAMS.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Availability</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading (water levels, surge)</td>
<td>External models, data</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>National DTM</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defence location (+ attributes)</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crest Levels</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toe Levels</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breach location</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property data set</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Socio-economic data</td>
<td>Environment Agency</td>
<td>any</td>
<td>any</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.3 Methodology

7.3.1 Criterion “Input data”

Table 31: Review against criterion “Input data” for PAMS.

The PAMS tool is designed to take in water levels from any external source (e.g. models) and to use data which is provided through Microsoft Access databases, shape files and other ArcGIS compatible data.

7.3.2 Criterion “Methods”

The methods are based on a probabilistic approach to determining the flood risk and expected annual damages (£). The probabilistic approach is based on the Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) methodology (http://www.rasp-project.net/). The PAMS tool specifically focuses on the assets or system of assets, providing information on whether a given asset or asset property increases or decreases the flood risk.
The principle modules include:
- An inspection Methodology (revised to gather key asset information);
- Hazard Indexing (simplified approach allowing approximation of risk);
- Analysis Engine based on aforementioned RASP methodologies (for defence performance and flood risk, including structural deterioration);
- Decision Approach (using multi-criteria analysis); and
- User Interface (GIS-based approach).

The area of flood inundation may be determined from (i) simple empirical formulae; (ii) 1D routing in the absence of defences; (iii) quasi-2D floodplain flow or (iv) 2D/3D hydrodynamic models i.e. the system is model independent.

The assessment will include multi-criteria analysis techniques, covering recreational amenity, economic damage, risks to people, health and safety of asset users, ecology, environmental degradation (habitat, water quality, landscape) and navigation. It may also make use of the evolving concept of Appraisal Summary Tables.

### 7.3.3 Criterion “Uncertainty”

Uncertainty will be incorporated using uncertainty propagation techniques which will highlight the uncertainty in outcome associated with a given course of action, and the key issues contributing to this uncertainty, thus providing a useful insight to the decision-maker.

### 7.4 Presentation

#### 7.4.1 Criterion “Target end-users”

The target end-users are summarised in Table 32 below.

<table>
<thead>
<tr>
<th>DSS</th>
<th>End-user</th>
<th>Knowledge level</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAMS</td>
<td>EA’s Regional and Area flood risk management teams</td>
<td>Basic</td>
</tr>
<tr>
<td>PAMS</td>
<td>EA’s Area Operations Delivery</td>
<td>Basic</td>
</tr>
<tr>
<td>PAMS</td>
<td>EA’s Corporate &amp; Planning</td>
<td>Basic</td>
</tr>
<tr>
<td>PAMS</td>
<td>Internal Drainage Board</td>
<td>Basic</td>
</tr>
<tr>
<td>PAMS</td>
<td>Local Authorities</td>
<td>Basic</td>
</tr>
<tr>
<td>PAMS</td>
<td>Indirect users – Water Companies</td>
<td>-</td>
</tr>
<tr>
<td>PAMS</td>
<td>Indirect users – Network Rail</td>
<td>-</td>
</tr>
<tr>
<td>PAMS</td>
<td>Indirect users – Energy Networks Assoc.</td>
<td>-</td>
</tr>
<tr>
<td>PAMS</td>
<td>Indirect users – policy makers</td>
<td>-</td>
</tr>
<tr>
<td>PAMS</td>
<td>Indirect users – process makers</td>
<td>-</td>
</tr>
</tbody>
</table>

*EA = Environment Agency

#### 7.4.2 Criterion “Visualisation”

The decision support information is provided in terms of flood risk metrics such as people risk, expected annual damages and environmental impacts. These are spatially differentiated and available at each time.
Table 33: Review against criterion “Visualisation” for PAMS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Static visualisation</th>
<th>Dynamic visualisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAMS</td>
<td>t, m, d</td>
<td></td>
</tr>
</tbody>
</table>

Figure 12: An example of mapped output showing critical linear defences.

Figure 13: An example of the output showing critical elements of an asset.

7.5 Technological Realisation

7.5.1 Criterion “Software architecture”

The PAMS system is designed with an open architecture (allowing individual modules to be revised independently) to enable the input of appropriate information about such issues whether directly or indirectly (e.g. via RASP/MDSF or other spatial models).
Table 34: Review against criterion “Software architecture” for PAMS.

<table>
<thead>
<tr>
<th>DSS</th>
<th>Modular interfaces</th>
<th>Interfaces</th>
<th>Model coupling</th>
<th>Development environment</th>
<th>Code accessibility</th>
<th>Program language</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAMS</td>
<td>y</td>
<td>n</td>
<td>ArcGIS</td>
<td>y</td>
<td></td>
<td>Visual Basic</td>
</tr>
</tbody>
</table>

7.6 Others

7.6.1 Criterion “Application”

The PAMS DSS is still under development, due for completion in June 2008. A key development task will involve the application to pilot sites.

7.6.2 Criterion “Weaknesses and strengths”

The key strengths of the PAMS DSS are that it will:
- fully represent the Flood Risk System through the Source, Pathway, Receptor, Management Response and Decision Support modules
- is model independent;
- it considers the reliability and failure modes of defences;
- includes multi-criteria analysis;
- will have a module for estimating the propagation of uncertainty
- is not restricted by temporal or spatial scales;
- provides a valuable system for establishing which assets or systems of assets are at risk;
- provides economic data regarding expected damage.

The weaknesses of the PAMS DSS are that it will:
- it requires detailed asset data including information about their condition, make, crest levels, toe levels and standard of protection;
- provides a probabilistic predictions – these have inherent difficulties associated with understanding and for validation

For further information on PAMS, see http://www.pams-project.net/.
8. Other non-UK specific tools

The DSS tools in this section were not developed specifically in the UK or as part of European Projects that HR Wallingford was involved in. These tools are reviewed for completeness however discussion is restricted to information available in the public domain.

8.1 RAMFLOOD

The Ramflood DSS tool is an output of the EC 5th Framework Project Ramflood, which included six partners from Spain, Germany and Greece. The project aim was to develop and validate a new web-based decision support system for the risk assessment and management of emergency scenarios due to severe floods. This entailed combining advanced information technologies with advanced methods for collecting, processing and managing hydro-geological data, qualitative methods based on simplified models and more complex computer simulation models, graphical visualization methods and artificial intelligence techniques. This was in order to provide comprehensive support to improve the process and outcome of decision making in flood management and risk assessment during the different stages of planning, flood fighting and post flood recovery.

The product is a Web based decision support system, that is, the end-user can work with it through a Web browser. It includes the following utilities:

- Flood hazard analysis on a study area in real time.
- Access to flood related information.
- Users' communication tools.
- New projects development tools.
- Users' management.

The Ramflood DSS tool has an open architecture (Figure 13 and 14). The development is based on an original approach identified as the intelligent decision support architecture. The Ramflood model base includes some simple hydrologic forecasting tools and allows for the integration of alternative existing tools and others which are in the process of development.

![Flow chart of the Ramflood DSS information flows.](image-url)
8.2 ANFAS

8.2.1 Description
ANFAS is a decision support system developed as part of a joint IST project between the EU and the People’s Republic of China. The system can be used by decision makers and stakeholders to simulate river floods and estimate the potential impacts.

8.2.2 Architecture
A key characteristic of the integrated system is that it is web-based with a distributed architecture. This architecture was adopted because (i) with the storage of all data on the server, data updates are immediately available to end users and (ii) since the numerical models often require excessive computational time the models can run on a separate computer dedicated to the task. In order to compare flood scenarios and assess the impacts, it integrates different modules in a transparent way for the user:

- Remote sensing / computer vision. The topographic data is prepared from a variety of sensors e.g. SAR, LiDAR, SPOT.
- Geographic Information System (GIS) databases
- Numerical hydraulic models. The existing models are CARIMA (1/1.5D) and FESWMS (2D).
- Impact assessment procedures. This is where the results are used to evaluate the impact of the flood on the surrounding area.

Users have the capability to replace some models with their own, including data sets.

8.2.3 Data
Data of various nature (topographic, hydrologic and socio-economic) and different acquisition techniques (ground survey, airborne and satellite remote sensing) are fused and integrated in specific data bases to be used in the different modules.
8.2.4 Visualisation
Extensive visualization capabilities have been implemented and end users can visualize the results in terms of graphs or maps on the web or download them on their PC using specially designed software.

8.2.5 Application
The system was tested in three pilot sites: the Loire river in France, the Vah river in Slovakia and the Yangtze river in China (Pratacos et al, 2006).

8.2.6 Target End Users
The ANFAS target user group is technical staff, managers, stakeholders and decision makers who have background in floodplain management and could interactively use the system and interpret its output. It is not intended for highly skilled hydraulic experts or modellers.

8.2.7 Measures & Decision Support
Decision makers must determine what are the most appropriate structural or non-structural measures to take in order to prevent floods and mitigate their impact. ANFAS includes facilities that permit users to define scenarios that consist of modifications in the hydraulics structures and perform “what-if” simulations.

8.3 MIKE 11 DSS

8.3.1 Description
The MIKE 11 DSS was developed by the Danish Hydraulic Institute (DHI) in Denmark. It is used at a planning level in assessing proposed flood mitigation options and preparing environmental impact assessments. It provides a strategic integrated Flood Plain Management approach, and it incorporates the 1D hydraulic modelling software MIKE 11 for flood analysis and flood plain management. The DSS considers the full impacts of flood extents, flood depths and flood damage of present or future options, i.e. "What if" scenarios can be modelled. The MIKE 11 hydraulic mode is linked to ArcGIS within a DSS framework. This enables presentation of flood inundation...
maps, flood impact maps and related statistics. Figure x provides an overview of the various utilities.

8.3.2 Target Users
The use of the MIKE 11 DSS is aimed at hydraulic modellers. The modeller presents the results to decision makers at all stages of the integrated process.

8.3.3 Visualisation
The map illustrates the results from model simulations in a visual format, facilitating interpretation and analysis of potential impacts. Several flood maps can be merged into a video, which animates to an example the development of flood inundation during a flood event.

8.3.4 Use of Output
The outputs are used for Environmental Impact Assessments, Flood Risk Analyses, Flood Damage and Disaster Assessments.

8.3.5 Data
The floodplain topography is essential. The MIKE 11 - GIS interface also allows for extraction of flood plain topography from the Digital Elevation Model (DEM).

![DECISION SUPPORT SYSTEM](image)

Figure 17: MIKE 11 DSS Flow Chart.

8.4 EFAS
The European Flood Alert System (EFAS) is a European Commission product, currently under development, which builds upon the European Flood Forecasting System (EFFS) and is intended to complement national flood forecasting systems. It is an activity of the Joint Research Centre of the European Commission together with meteorological services and Water Authorities of the Member States and Candidate Countries. The aim is to develop a prototype EFAS that will be tested and validated during the EC 6th Framework Programme. It will provide:
- an overview of forecasted river discharges across Europe
EFAS incorporates the LISFLOOD modelling software, which is a spatially distributed water balance model that will form the backbone for detailed modelling practices in different regions in Europe or for individual basins. It has been adapted to run for the whole of Europe with a horizontal resolution between 1 and 5 km.

A prototype of EFAS for the Elbe and Danube catchments is expected to be ready and tested by 2006.

For further information on EFAS, see http://efas.jrc.it/index.html.
9. Conclusions

The review of the DSS tools has highlighted a number of issues for the development of DSS tools. Table 35 provides the key findings.

Table 35: UK DSS conclusions

<table>
<thead>
<tr>
<th>No.</th>
<th>Topic</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Decision support</td>
<td>(i) The DSS should be decision specific i.e. not try to support / solve too many things</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ii) The evidence provided to the user should be “rich” e.g. enabling the user to explore the basis of the evidence presented.</td>
</tr>
<tr>
<td>2</td>
<td>Flexibility</td>
<td>The DSS should be appropriately flexible (but not designed to be flexible for the sake of it.)</td>
</tr>
<tr>
<td>3</td>
<td>Open/closed Architecture</td>
<td>The system architecture appropriately open/closed for the decision at hand and the mode of use. (Open architectures are not always the most beneficial e.g. in long-term planning it may be appropriate to have embedded hydraulic models).</td>
</tr>
<tr>
<td></td>
<td>Model coupling</td>
<td>A modular approach is recommended where possible. For example, the DSS should provide the user with the option of using default methods / embedded models or entering results from more complex externally run models or information.</td>
</tr>
<tr>
<td>4</td>
<td>Scale</td>
<td>The DSS should be independent of temporal and spatial scale (typically this is easily accommodated with the use of GIS)</td>
</tr>
<tr>
<td>5</td>
<td>Use of risk-based methods</td>
<td>The DSS should reflect the policy context within which the decisions will be made. As the policy moves towards risk management then the DSS should enact risk-based methods that provide a rich evidence to the user on both probability and consequence.</td>
</tr>
<tr>
<td>6</td>
<td>Use of probabilistic approach to risk</td>
<td>The UK strongly advocates a probabilistic approach to risk and this should be reflected in the DSS. This helps ensure that the evidence presented to user is appropriately robust and meaningful. A probabilistic method should be appropriately reflected across all aspects of the source, pathway and receptor and not simply applied to only one or two elements of the flood risk system. (Within the NaFRA tool supported by RASP multiple combinations of load, defence failure, inundation and damage are considered).</td>
</tr>
<tr>
<td>7</td>
<td>Presentation of outputs</td>
<td>The representation of output risk metrics should be clear whilst reflecting the complexity of the underlying analysis. This typically involves the high level aggregation of data into useable evidence. For example, decision makers value basic information on the spatial distribution of risk, and the attribution of that risk to particular assets and driving uncertainties. This helps the targeting of investment.</td>
</tr>
<tr>
<td>8</td>
<td>Uncertainty</td>
<td>(i) Uncertainty should be explicitly handled and appropriately disaggregated.</td>
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<td>(ii) It should be expressed in a manner which is accessible.</td>
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<td>(iii) Guidance should be provided on the interpretation and use of this information.</td>
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<td>9</td>
<td>Uptake and use</td>
<td>The UK has seen wide uptake and use of two DSS tools in recent years:</td>
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<td>(i) MDSF (Strategy Planning Tool)</td>
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<td>(ii) NaFRA (National Flood Risk Assessment Tool)</td>
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<td>The main reasons for this are:</td>
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<td>(i) User support – this includes general guidance and advice in the form of manual, website, Help Menu. Query hotlines with a 24 hour response time.</td>
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<td>(ii) Training should be provided on request.</td>
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<td>(iii) Software maintenance which includes the release of new versions, upgrades, bug fixing, changes resulting from feedback from user group meetings etc.</td>
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<td>(iv) Use of national data sets such as the Digital Terrain Model, the river network, social vulnerability indices etc. which are supplied with the software e.g. MDSF.</td>
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<td>(v)</td>
<td>Advocated by the appropriate authority / Agency (e.g. Environment Agency of England and Wales) i.e. the consultants are required to use these.</td>
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<td>(vi)</td>
<td>Include a variety of calculations e.g. agricultural damages, coastal erosion metrics etc.</td>
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<td>(vii)</td>
<td>Automate tedious calculation processes at National (NaFRA) and Catchment (MDSF) scale.</td>
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</tbody>
</table>
10. References

10.1 Reports / Papers


10.2 URLs


