Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme

Scoping the development and implementation of flood and coastal RASP models

(RASP - Risk Assessment for System Planning)

R&D Technical Report SC050065/SR1

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Environment Agency

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Department for Environment Food and Rural Affairs

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- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements.
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Steve Killeen
Head of Science

Executive summary

The Environment Agency, Defra and other stakeholders have similar aims regarding flood risk management (FRM). The Government's 'first response' to the Making Space for Water consultation set out the strategic direction of travel on a number of key issues. The aim of this new strategy is:

To manage risks from flooding and coastal erosion by employing an integrated portfolio of approaches which reflect both national and local priorities, so as
- *to reduce the threat to people and their property;*
- *to deliver the greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles.*

To secure efficient and reliable funding mechanisms that deliver the levels of investment required to achieve the vision of this strategy.

Meeting these aims will require answers to some basic questions, including:
- What are the drivers and pressures on flood risk, now and in the future?
- How do flooding systems work? How do flooding systems respond to the loads imposed on them?
- What is the risk, or probability and impact, of flooding?
- How does risk vary throughout the floodplain?
- How can risk be managed most efficiently and effectively, using the full 'basket' of FRM measures?

Risk modelling has a key role to play in answering these questions. The aim of this study is to help to plan the development and implementation of modelling tools for flood risk assessment to support FRM planning and decision-making.

The project has produced the following, as a result of extensive consultation, analysis and deliberation:
- an overview of the underpinning concepts of Risk Assessment for System Planning (RASP)[1];
- an overview of the decision making processes for flood risk management, and the role of risk assessment and management;
- identification and description of existing RASP methods and tools;
- proposals for future developments of the RASP tools and models to meet FRM customer needs, and to help to meet the aims set out in Making Space for Water.

A key conclusion is that RASP methods already support a range of purposes, using a common approach to assessing flood risk, but that more widespread use is possible. To provide the most effective support, RASP will need to be embedded within a number of planning processes and tools. These will share common data and computation modules as appropriate. This report identifies three key challenges that will need to be met before RASP methods can be successfully used in practice:

- RASP methods will need to be applied to a wide range of practical situations so that their utility in the decision-making process can be demonstrated and evaluated.

[1] Formerly used for 'Risk Assessment for Strategic Planning' but now redefined to reflect the changed purpose of risk modelling tools. In most cases in this report the new meaning is used. Where the old meaning is use, this should be clear from the context.

- To ensure that the existing RASP methods are implemented as part of day-to-day practice, appropriate policies and supporting business processes will need to be established. Projects such as NaFRA, MDSF2 and PAMS are starting this process but it will need to be continued.
- The science of RASP will need to be extended to support the delivery of the holistic management of water-related risks outlined in Making Space for Wate*r*.

This report has some clear recommendations for RASP-related research and development. These include proposals for development of decision-specific tools, covering national policy planning, strategic planning, asset management, development control and flood incident management. These research recommendations will be reviewed and developed as appropriate with the relevant business partners – clearly any future development would need to be supported by a full appraisal of benefits, costs and risks.

The project also makes recommendations for further research, including research into sources, pathways and receptors, as well as systems analysis frameworks, decision support and software tool development. The recommendations will be carefully considered by Defra and the Environment Agency, as we develop and implement the joint R&D programme.

Finally, the RASP approach described here can only be successful if we have high quality knowledge, information and data on a wide range of flood-related processes. In particular, it depends on hydraulic, statistical, social, environmental and economic know-how. Many related projects and programmes support the Defra/Environment Agency programme and are providing the basic knowledge, understanding and tools on which good quality risk assessment and management relies. Incorporating these new sources of information and data into the ongoing development of the RASP methodology will be central to successful implementation of flood and coastal risk management.

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- Phil Marshall (Area FRM)
- David Murphy (Risk and Planning)
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1 Introduction

1.1 Background

Defra and the Environment Agency are adopting a risk-based approach to flood and coastal erosion risk management (FCERM). The 'Making Space for Water' (MSfW) strategy (Defra, 2005) and the Environment Agency's 'Strategy for Flood Risk Management' define an improved approach to decision-making, communication and delivery of FCERM.

These strategies suggest flood and coastal risk management will need to be economically, environmentally and socially sound, taking into account both the probability and the consequences of flooding. Solutions should be developed from integrated portfolios of both structural (e.g. asset management) and non-structural (development control and flood incident management) responses. A consistent approach will be adopted for planning, implementation, monitoring and improvement of flood and coastal erosion management at national, catchment, coastal cell or local levels. We need to ensure that today's developments in policy, process and operational practice promote these aims, while meeting the longer-term challenges such as climate, socio-political-economic and science-technical changes and related uncertainties.

The Environment Agency and Defra have therefore become increasingly focused on the use of integrated, risk-based system approaches for FCERM. These look beyond physical flood defences to include the whole range of flood risk management (FRM) options. With the right tools and information, the Government, operating authorities and others should be able to manage risks better, both now and in the future. This approach promises to deliver more sustainable solutions or efficient decisions at particular special or temporal scales.

Put simply, the aim is to deliver more risk reduction per pound, and create a better environment for all. This report is concerned with tools that help to make decisions to make this happen.

1.2 Context

To implement the new approaches, meet challenges and make changes, decision-makers and operators need good evidence and appropriate innovation based on sound science. The science should be practical and based on the best available data, to provide improved models and new tools. The Modelling and Risk (MAR) Theme within the joint Defra/Environment Agency R&D programme responds to evolving science needs of FCERM.

Previous R&D within the joint R&D programme has set out a vision for the development of a coherent, user-focused family of risk-based assessment and decision support tools for Flood and Coastal Risk Management (Environment Agency, 2002). This vision has been realised, in part, through a range of R&D projects and programmes, many of which are identified in Appendix 1.

The development of the Risk Assessment for System Planning (RASP)[2] methods, which commenced in 2001, was commissioned in direct response to this stated need. The initial

[2] To reflect the changing role of the RASP methods the associated acronym has been changed from 'Risk assessment for strategic planning' to 'Risk assessment for system planning'.

RASP research (Environment Agency, 2004) provided a hierarchical risk-based analysis framework to help the Environment Agency and Defra assess flood risk and prioritise investment in flood risk management. These first generation risk-based methods have continued to evolve since 2004 and are now reaching maturity. It is now appropriate to seek to implement these existing methods into specific decision support tools and initiate the next generation of scientific development.

This report provides a framework within which the existing RASP methods can be implemented and taken forward to meet the challenges set out in Making Space for Water (Defra, 2005).

The aim is to improve existing RASP - related tools/models, and to communicate the links and vision to a range of users. Examples of current RASP-related models include 'RASP', 'Modelling and Decision Support Framework' and 'Performance-based Asset Management System' (PAMS).

The report has two basic perspectives:

- It describes the system risk tools available now to support a range of FCERM decision-makers.
- It describes a series of recommendations to improve these tools in future and to encourage their uptake.

The first perspective clarifies what tools are available and what their roles are. The tools have been developed for a range of purposes over the years and it is now important to lay out a clear framework so users have a simpler and more consistent view of the tools and how they are related. This should help to remove any confusion that currently exists.

The second perspective describes developments needed to fill the gaps – in particular, what are the high priority end-user needs and what are the most important outstanding research areas?

1.3 Project scope, objectives and work packages

This project has three primary objectives:

- To provide an overview of the existing RASP methods and underpinning concepts.
- To outline a framework for the efficient implementation of the existing RASP-related R&D outputs into the Environment Agency so that the benefits of the earlier R&D can be realised.
- To set out the direction of future developments of the RASP tools and models to meet the FRM customers' needs and the challenges laid out in Making Space for Water.

The project was carried out within five work packages:

- WP1 – to establish and find out and publicise the availability and the linkages between different RASP related tools and models developed under different themes and partnership projects for implementation.
- WP2 – to explore reasons for the barriers to and opportunities for the uptake of the modelling tools within industry.
- WP3 – to identify the research need/knowledge gaps for risk assessment for strategic planning – modelling and the delivery of FCERM.
- WP4 – to produce 5-year MAR R&D Theme work plans for RASP- related or integrated system models and applications.
- WP5 – to communicate the links and vision to a range of users.

Software modularity and implementation issues associated with any future RASP tools are considered in a sister report under Project FD2121.

A scoping study on broad-scale process modelling is under way in Project FD2118. Scoping studies on catchment, estuary, coastal, urban and groundwater systems are also in progress. These aspects are not considered in detail in this report – though all form part of a programme to improve our knowledge of flood and coastal processes. They are relevant because any further research will lead to improved understanding. This will bring improvements in the quality of information that forms such a vital part of flood and coastal risk assessment and management.

The findings of this study will be taken forward under the umbrella of the Environment Agency's Flood Risk Management Modelling Strategy, currently under development.

1.4 Target audience

The report is aimed primarily at Environment Agency and Defra staff, including policy, process and science teams. The report will also be of interest to other stakeholders with a role in flood risk management.

1.5 Outline of the report

Following this introductory chapter, the report is structured as follows:

Chapter 2 – An overview of the decision-making process (in the context of this report).

Chapter 3 – An overview of the RASP concept and methods.

Chapter 4 – An overview of the existing RASP methods and tools that can be implemented within decision support tools.

***Chapters 5* and 6** – Recommendations for the further development of the RASP methods.

The report includes references, a list of abbreviations, and appendices of related research projects and potential data flows for NaFRA, MDSF2 and PAMS.

2 The decision-making process

This section presents, in outline, the current decision-making and planning frameworks relevant to this study. These include the generic management model in use in the Environment Agency and other organisations, and more detailed planning and delivery frameworks developed for flood risk management. We end with some comments about the ability of existing models to support these processes. This chapter therefore sets the context for modelling needs that are developed later in the report.

2.1 Overview of the decision process

The Government strategies and Environment Agency management systems drive continuous improvement (Figure 2.1). Flood risk management takes place as a process of continuous analysis, planning, implementation, monitoring, review, adjustment/improvement and/or adaptation. For this process, data, tools and techniques for risk assessment and decision-making are necessary (Figure 2.2).

Figure 2.1: The Environment Agency management system – driving continuous improvement

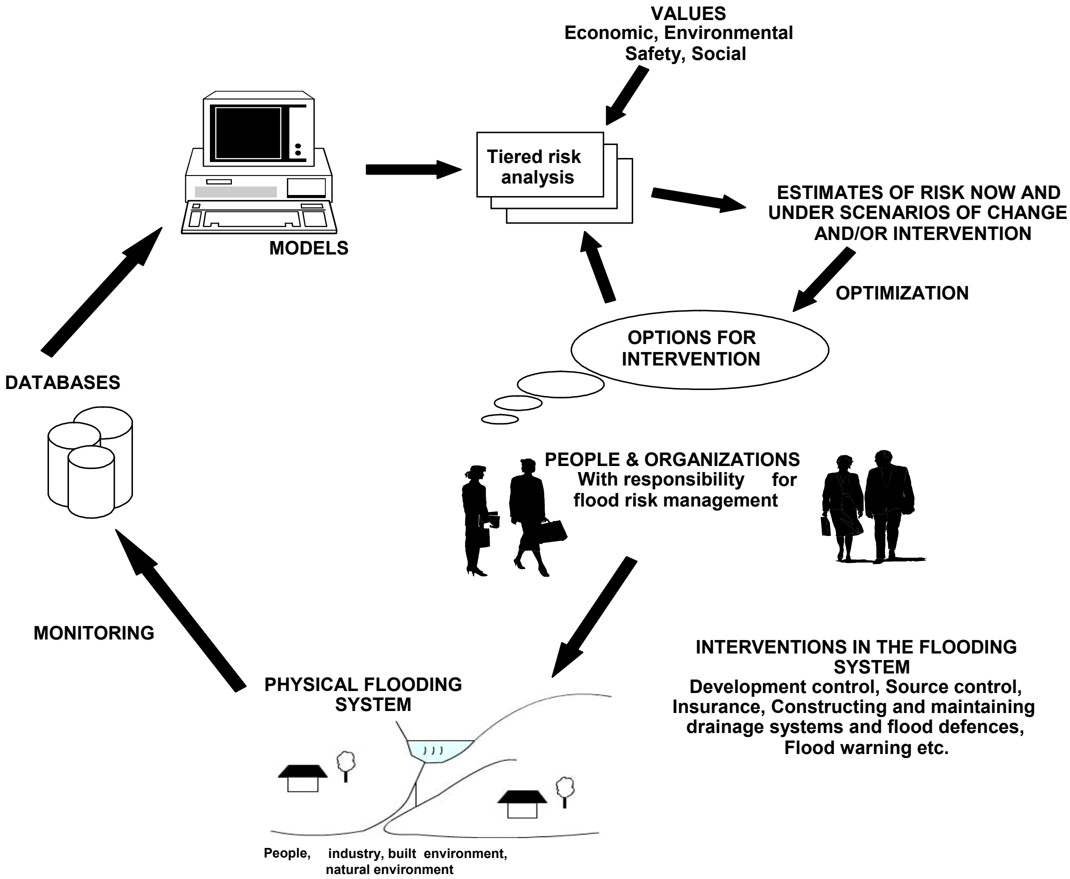


Figure 2.2: Flood risk management is a cyclic and dynamic process of analysis, adjustment and adaptation (after Hall *et al*., 2003)

Within this continuous cycle the Environment Agency has identified a series of levels at which flood risk management planning and decision-making takes place (Figure 2.3). The hierarchy of decision-making shown in Figure 2.3 is enacted through a series of specific 'plans' (Figure 2.4). Decisions are then made within the context of these plans and hence any risk assessment and decision support tools must assist them.

As highlighted in Figure 2.4, strategic planning performs a pivotal role in the system planning process. The understanding of the system, risk assessment, option appraisal and planning decisions made under the heading of strategy planning (including Catchment Flood Management Plans (CFMPs), Shoreline Management Plans (SMPs) and Strategy Plans) set the direction of different management interventions and responses. This includes asset management, regulation, development control and flood event management for a specific region, catchment or coastal cell/sub-cell. In turn, the development of the strategy takes its lead from clearly articulated national policies (based on reliable evidence on risk, perceived societal preferences and resource constraints). As the more detailed Delivery Plans are completed (including for example system asset management, development control and flood event management planning) an improved understanding of the behaviour and investment needs of the flooding system are fed back into the higher level plans.

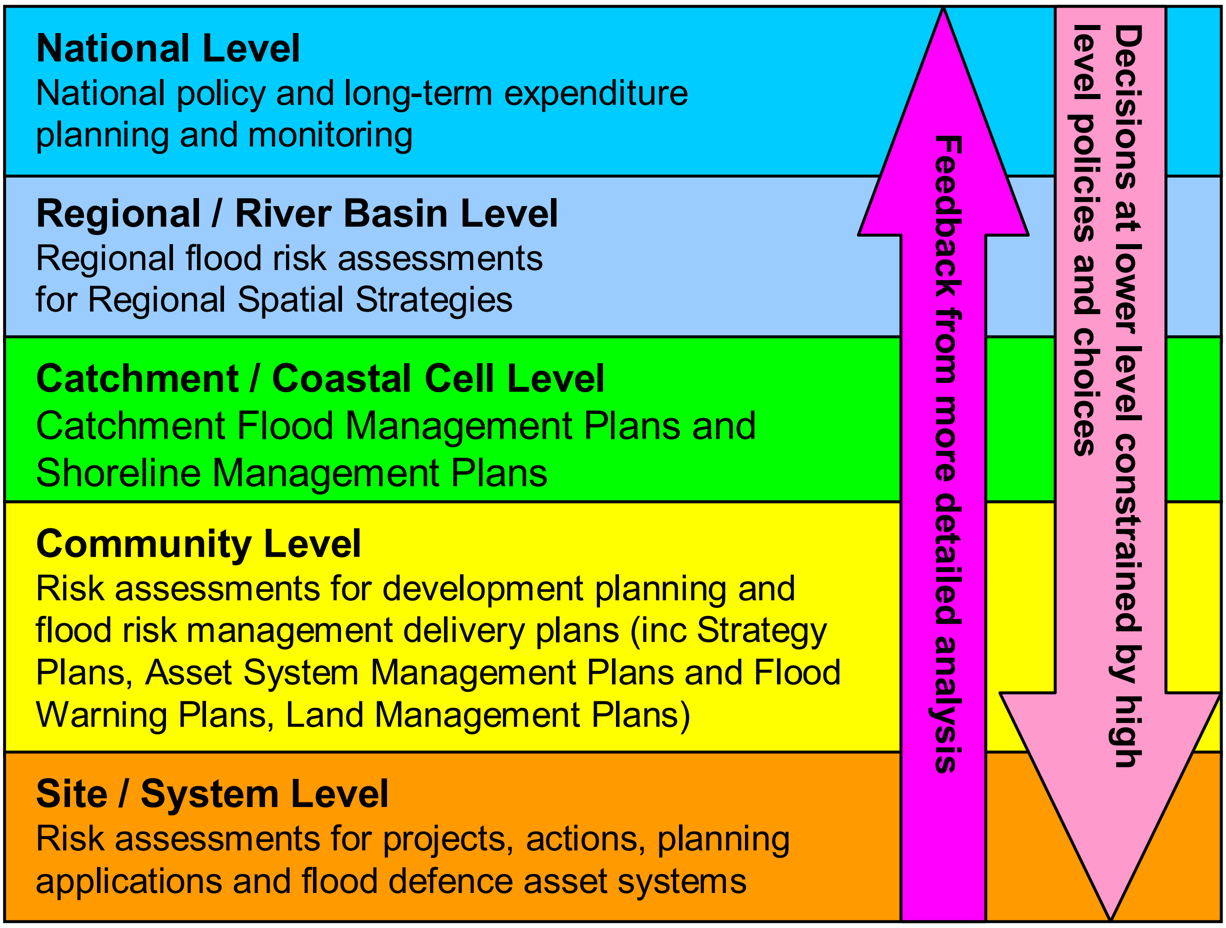


Figure 2.3: Planning levels recognised within the FCERM community

For the planning and decision making processes to be effective, consistent tools and techniques for risk assessment and decision-making are necessary.

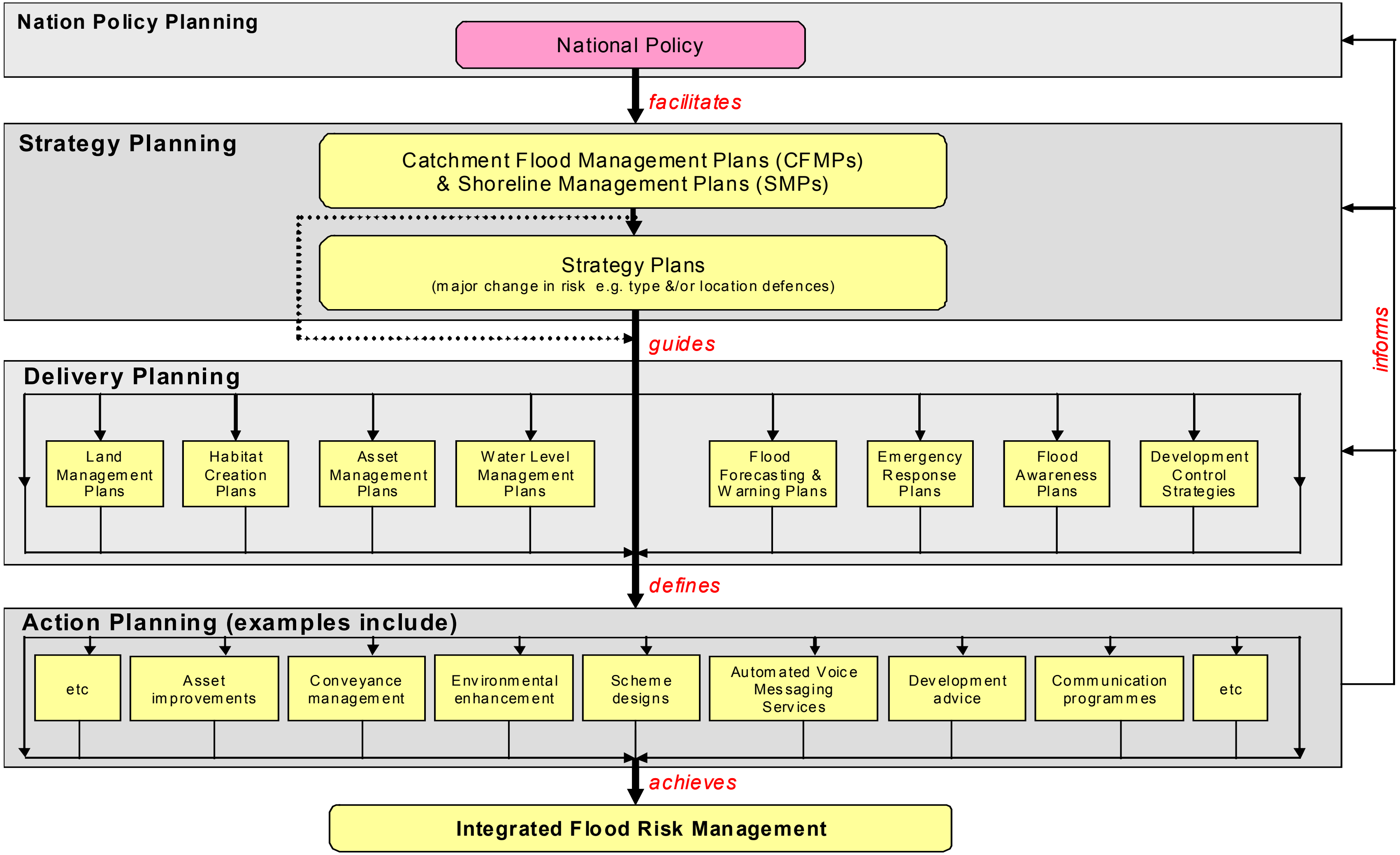


Figure 2.4: An overview of the FRM plans that support the delivery of integrated flood risk management within the Environment Agency. (This chart is under development – the version shown is correct at time of writing but subject to change)

2.2 Types of risk model – an overview

The planning and delivery frameworks are currently supported by a range of models. The Environment Agency's modelling strategy, currently being developed, will provide a framework to guide the development, dissemination and use of models within the Environment Agency. In the meantime this short section gives a broad taxonomy of the key types of model designed for probabilistic flood risk assessment, and suitable for the type of system analysis relevant to this project. These models are all interrelated and share many common elements. Placing them in distinct categories can be misleading since the boundaries are fuzzy, but it does help to draw out the similarities and differences.

System risk analysis. These models attempt to include all elements of the particular flooding system to assess the likelihood of flooding. At their most detailed, they may include full hydrological, hydraulic, structural, inundation and consequence modelling. In practice, simplified models may be used for some system components. The design of these system models is rather specialised as choices must be made about which processes or system components to represent most accurately. The models can also include joint probability of flooding from multiple sources. Their output is probabilistic – i.e. results show the overall probability that a particular location in the floodplain will flood in a given time period. The models are run for many loading and defence failure scenarios to build up a picture of the flood probability throughout the floodplain. The main output is therefore a probability 'field' or grid, flood depths and velocities together with associated risk metrics. These can be annually averaged or provided for each return period load event.

The probabilistic nature of the output from this analysis has implications for verification – for example the annual NaFRA studies provide expected annual flood damages and probabilities but we have no 'observed' probabilities to check against. This is perhaps an area that needs more attention in future.

Referring to Figure 2.4, the RASP models are typically used in this mode for national policy planning, and are being developed for strategy planning through MDSF2. Elements are also being developed for asset management planning at the 'delivery planning' level through PAMS.

System scenario analysis. These models attempt to represent the impact of a specific event or scenario – typically a realistic storm surge event or rainstorm – over a wide area. As with system risk models, they aim to represent the flooding system in a relatively complete way. An advantage over the system analysis models is that the flood impacts are directly attributable to the modelled scenario. In other words, the scale and extent of flooding due to a particular event is preserved in the model. While not inherently probabilistic since they are driven by 'deterministic' scenarios, the models can be supplied and run with multiple scenarios to build up a probabilistic result.

This type of model is often used to explore the impact of catastrophic events.

Hydraulic models. Most flood models used for feasibility, appraisal and design are, at their core, numerical simulators of flow. Boundary conditions are set by hydrological, tidal or marine conditions. Traditionally they were used only for main channel applications, but advances coded into models such as InfoWorks and MIKE21 have enabled the models to represent flows across floodplains, and flood extents and depths. Hydraulic models are, typically, 'driven' by particular return period events and the impacts of these events assessed. Often, this provides outlines of flooding for each of the required return periods. In simple cases these may also give a reasonable picture of flood probability, but in more complex cases with defences and complex flood routes this may not be the case. Nevertheless this type of model is very well established, can be calibrated against known events and is familiar to many practitioners.

Hydraulic models are used mainly at the delivery planning level in Figure 2.4, and for real-time flood forecasting models where the aim is to predict occurrence of high flows, high boundary conditions, or flooding in order to issue flood warnings and prepare for emergencies.

Hydraulics models can also be embedded within 'system' flood risk models – either run offline to provide data on extremes, or more tightly coupled to assist with prediction of flood inundation for example.

Models – summing up

There is a general trend of convergence between the various types of model. Traditional hydraulic models now include flood inundation and form the basis of the Environment Agency flood zones and extreme flood outline. The national flood risk map, produced using a system risk model, provides a more detailed picture and includes the effects of defence performance, but for simple undefended rivers these methods should give similar results. Different types of system model share a lot of common elements such as use of fragility curves.

Nevertheless there are still genuine differences, both in the way that models are used and in model structures. That is understandable bearing in mind the wide range of needs illustrated by Figure 2.4. We should be aiming to exploit the strengths of different models and maximise the sharing of common modules and data. We should also be aiming to converge on common result formats, for example to reconcile the 'return period contours' provided by many flood models with the 'probability fields' provided by system risk models.

The bulk of this report is now concerned with system risk models. As the Environment Agency completes and implements its flood modelling strategy we should see a more coherent and, where appropriate, converging path for developing and implementing the whole range of flood risk models outlined above.

3 Overview of the RASP concept and methods

This chapter provides an overview of the key principles of Risk Assessment for System Planning (RASP). We present three essential principles for RASP and discuss the importance to flood risk management of each principle. This chapter is not written with any specific model in mind, but instead aims to set out the main characteristics that risk models should have in order to make the most effective contribution to flood risk management. The status and range of application of RASP methods in current use is discussed in Chapter 4.

3.1 Introduction

Flood risk management aims to reduce the threat to people and their property; and deliver the greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles. RASP is a concept and an evolving method for tiered risk assessment for system planning and is, fundamentally, concerned with the provision of reliable and useful evidence for FRM decisions.

By enacting suitable models within a generalised methodology, RASP enables *sources* (including a wide range of extreme wave and water level combinations), *pathways* (including the performance of multiple defences expressed in terms of a fragility curve) and *receptors* (including people and property) of risk to be combined. The RASP tools therefore provide an important methodological step towards an improved ability to manage flood risk in an integrated way. The notion of a system-based analysis (considering sources, pathways and receptors) is fundamental to RASP. Equally important and implicit within the methods is the notion of hierarchy and appropriateness; where the complexity of the analysis reflects sensitivity of the decision being made to uncertainty and the availability of data and models.

The assessment of current and future flood risk and uncertainty is complex and is not a precise science. RASP therefore adopts a logical, structured and transparent approach based on three core principles, namely:

- **A systems-based thinking** – that considers all (appropriate) aspects of the flood risk system in a structured manner.

- **A risk-based approach** – that helps problem formation, risk assessment, option appraisal and risk management planning by seeking to target limited resources (time and money) to achieve maximum benefit (tangible and intangible).

- **A hierarchical process of analysis** – that seeks to provide assessments proportional to the risk, proposed decisions and spatial and temporal scale, while making best use of the available data and information.

These principles, and how they are addressed within the RASP methods, are considered below.

3.2 A systems-based approach

The first core principle of the RASP method is that it should be a systems-based approach. The benefits of this approach and the nature of the support provided by RASP are discussed below.

3.2.1 Why adopt a systems-based approach?

The flood risk system often exhibits significant spatial (from national level to local level) and temporal (current and future) complexity and consists of different sources, pathways and receptors for flood risk (Figure 3.1). A systems-based approach has many advantages over traditional methods in enabling the decision-maker to understand the behaviour of the system and how it might respond to an intervention. System-based thinking enables the complexity to be broken down without losing the behavioural characteristics of the system as a whole.

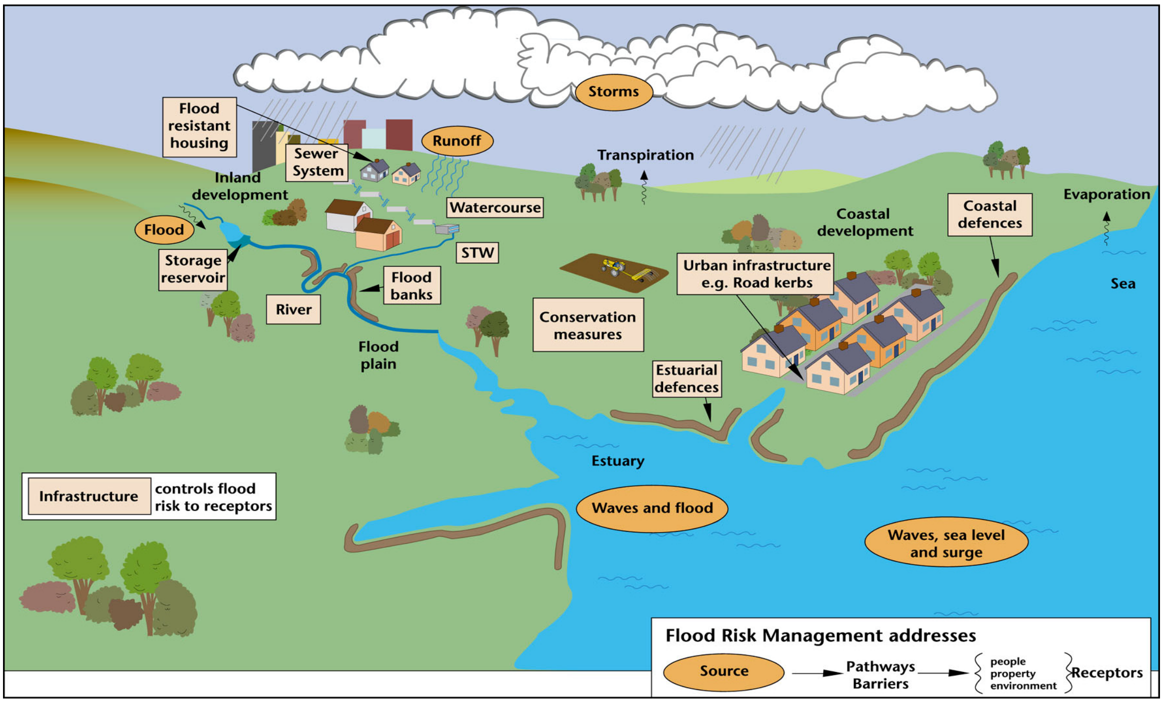


Figure 3.1: The flooding system often exhibits significant spatial complexity

The system state is described by a structured source-pathway-receptor (S-P-R) framework. The S-P-R conceptual model, widely used to assess and inform the management of environmental risks across government, provides a structured approach to the characterisation and conceptual simplification of the complexity inherent in many systems. The more generic S-P-R model has been translated into the context of flood management, as illustrated in Figure 3.2.

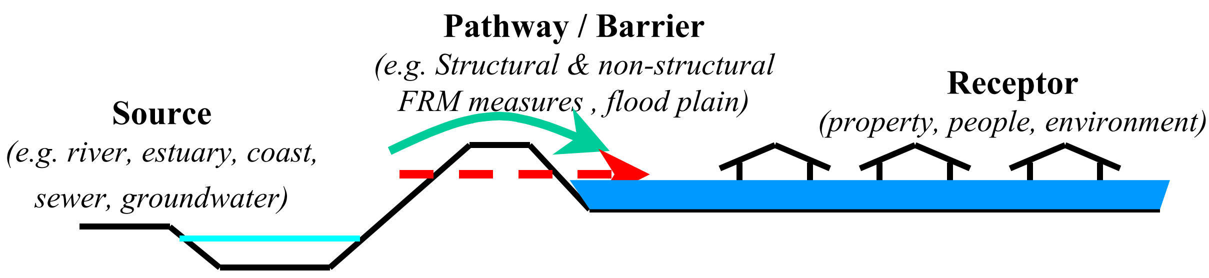


Figure 3.2: Simplified illustration of source-pathway-receptor concept

Sources – the meteorological factors that include rainfall, waves, surge and their associated probability of occurrence (singularly or jointly). In the future, other sources such as sewer flooding and groundwater water flooding should be considered.

Pathways and barriers – the behaviour of catchments and coastal zones, the nature, extent and condition of assets, topography and land use as well as the hydrological and hydraulic factors that determine the patterns and volume of run-off. Current models considering the structural barriers and in the future the non-structural FRM measures should also be considered.

Receptors – the exposure and vulnerability of the people, property and environmental features that may be harmed by a flood. (Note – currently the consideration of intangible impacts on people and the environment is limited. With time as information becomes available, the range of impacts considered can be extended without modification to the basic framework.)

The system state (described by the S-P-R framework) is and will be changed through time and in space by a combination of drivers and pressures as well as the FRM responses (Figure 2.1). To support robust FRM decisions the significance of these changes and efficiency and effectiveness of the possible management responses must be considered and understood. System-based approaches enable the influence of the factors that change the system state (both positive interventions by the flood risk manager and the external influences such as climate change) to be captured in a structured manner. This more dynamic description of the flood risk system can be defined by the so-called Drivers-Pressures-State of system-Impacts-Response (DPSIR) framework (Figure 3.3), where the 'system state' is, in turn, described by the S-P-R model introduced above (Figure 3.2).

3.2.2 How does RASP thinking fit within the DPSIR framework?

All of the tools using the RASP methodology demand an articulation of the problem within the context of a S-P-R framework. For any given system state (describing a unique combination of source, pathway and receptor conditions) within the DPSIR framework (Figure 3.3), the RASP methods enable the probability of that system state to be established and the associated impacts assessed (in economic or any other quantified terms) and hence risk calculated. This provides the user with the ability to undertake flexible 'what-if' testing by simply modifying a component(s) of the system and monitoring the change in risk.

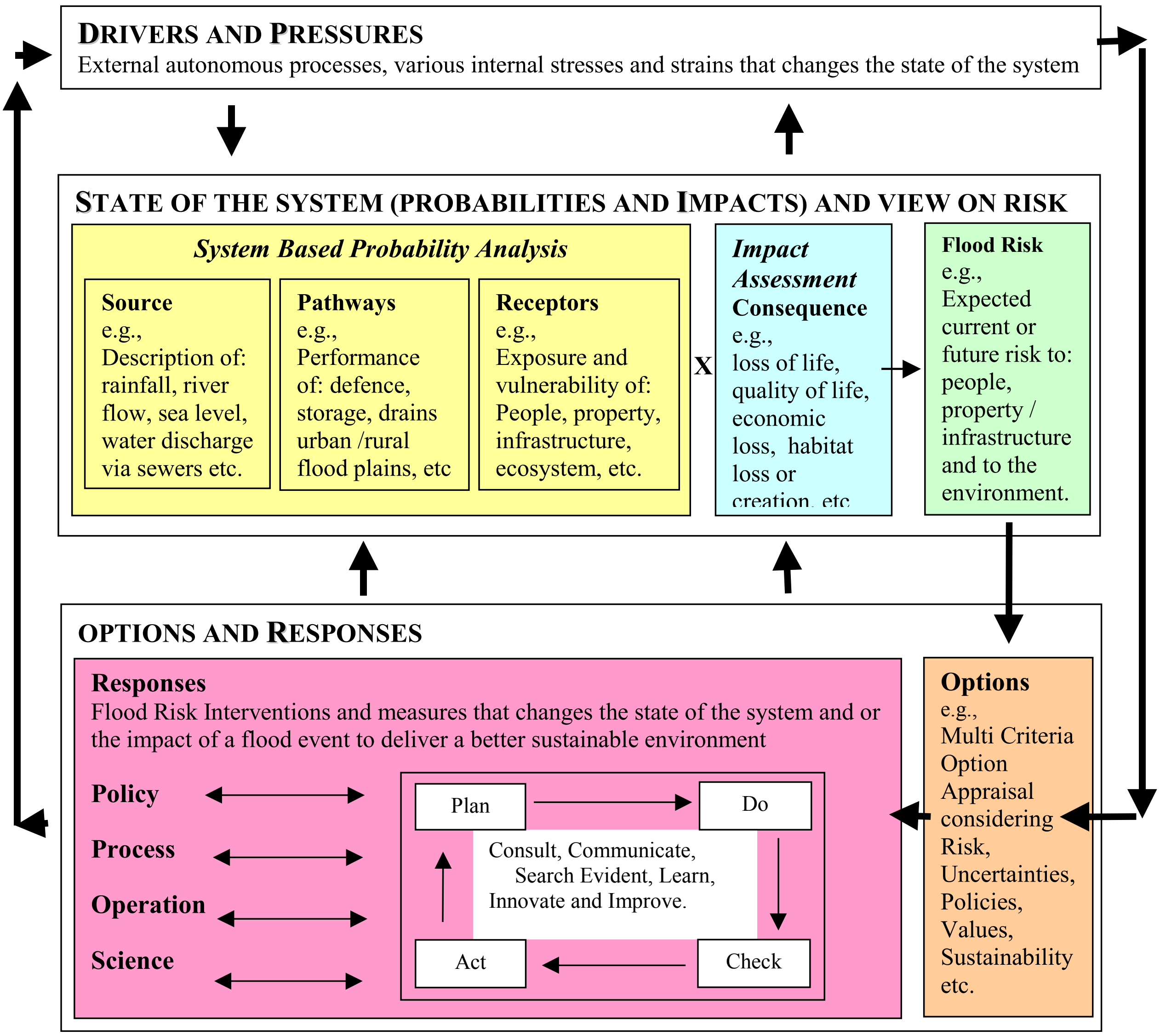


Figure 3.3: DPSIR framework

3.2.3 Is the current RASP approach future-proofed?

The S-P-R model will continue to offer a useful reference framework into the future, as the industry starts to embrace a more holistic view of flood risk. It will, however, be important to revise the definition of sources, pathways and receptors to enable this broader view to be captured within the modelling approach. In particular, it will be important to revise the S-P-R model so that:

- The 'source' terms include 'upstream' up to primary driving meteorological events. The 'pathway' terms become more inclusive of both urban and rural pathways and embrace the underground infrastructure and conveyance channel/foreshores as well as the above-ground defences and floodplains.

- The receptor terms become more comprehensive and are extended to include a full range of quantified impacts (including the environmental and social impacts – both short and longer term). An example of how the revised S-P-R model might look is provided in

Figure 3.4.

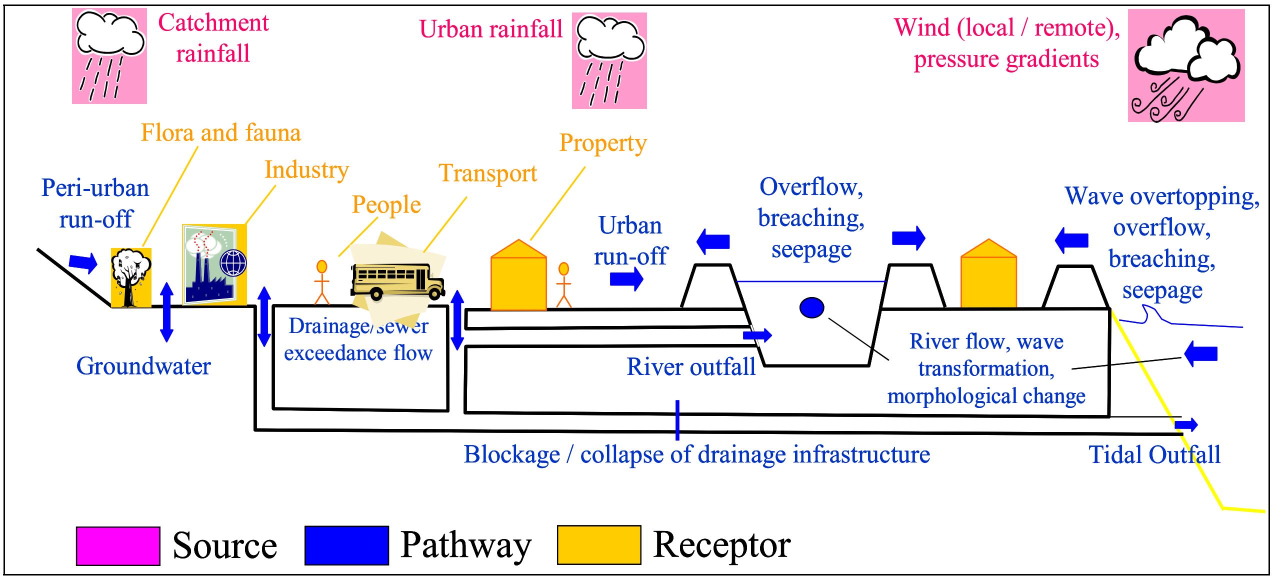


Figure 3.4: A more holistic view of sources/pathways and receptors as promoted by Making Space for Water (adapted from Hall *et al.*, 2006)

3.3 A risk-based management approach

The second core principle of the RASP methods is the use of a risk-based approach to flood management. A high level description of this risk-based management approach and decision process is shown in Figure 3.5 and the benefits of this approach and the nature of the support provided by RASP are discussed below.

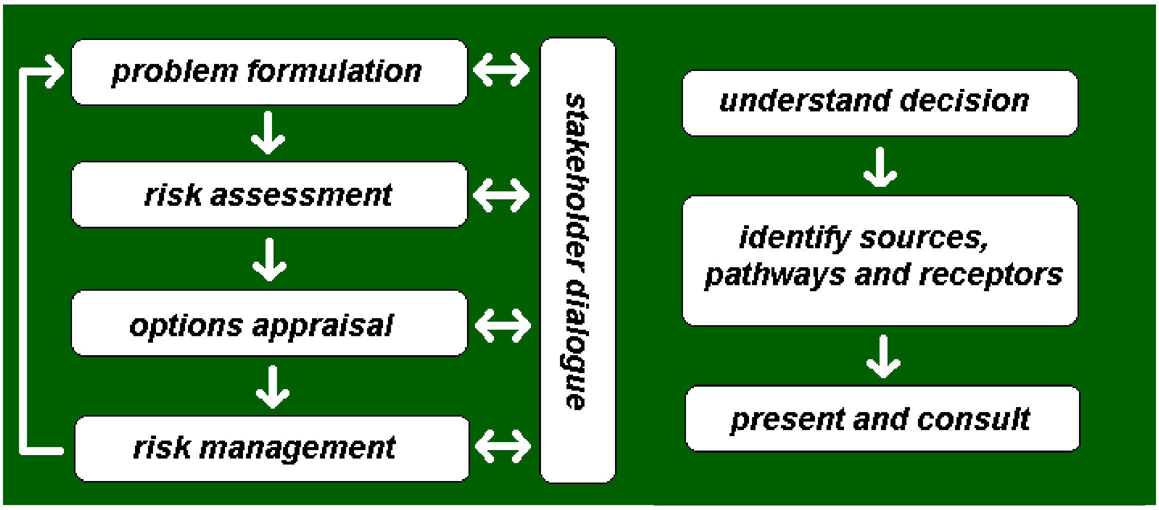


Figure 3.5: Flood risk management process – based on DETR/Environment Agency *Guidelines for Environmental Risk Assessment and Management* (2000)

3.3.1 Why adopt a risk-based approach?

It has long been recognised that flood risk cannot be eliminated completely and that an understanding and prioritisation of risk is key to improving risk management. In particular, a risk-based approach to management shifts the focus to *outcomes*: where decisions are made based on an assessment of the impacts of flooding and erosion, together with the likelihoods of those outcomes (Sayers *et al.*, 2002). This unlocks the potential for a more integrated approach to risk management in which a full range of co-ordinated interventions and responses can be planned and implemented.

In particular, this means deciding on the relative importance of actions such as:

- construction of new flood management infrastructure where it is most efficient in reducing risk;
- removal of FRM assets which can no longer be justified;
- maintaining and operating flood defence assets and asset systems to minimise risk;
- providing effective flood forecasting and warning where it is best able to minimise the consequences during a flood event;
- planning effective flood incident management as required under the Civil Contingencies Act;
- appropriately restricting development in flood risk areas to limit the growth in potential consequences;
- advising other FRM stakeholders under the Environment Agency's strategic role or supervisory duty, particularly as regards the attribution of risk to assets and hence responsible parties.

In the context of an integrated approach to risk management, risk-based methods help the decision-maker to focus on outcomes, remove bias from the analysis process and consider the dynamic nature.

- **Focus on outcomes**
  A risk-based approach is not new but one that has been advocated for many years. For example, a key aim of the Government's Making Space for Water and the Environment Agency's Environmental Vision is to reduce flood risk. Through the Environment Agency's Corporate Strategy and Strategy for Flood Risk Management the priorities to achieve this aim and deliver the targets set by Government are set out. Fundamental to this strategy is the adoption of a risk-based approach to flood risk management. This is a proactive approach where resources and efforts are targeted at the locations or communities where greatest benefits can be achieved. These benefits are framed in terms of reducing the probabilities and consequences of flooding, which together constitute the risk.

- **Remove bias from the analysis process**
  Traditionally, engineers have adopted a precautionary approach to risk and uncertainty. This may mean adopting a 'conservative' view of both the likely strength of a system (i.e. underestimating its resilience/resistance to flooding) and the likely loading on the system (i.e. biasing the analysis to overstate the wave and surge conditions). Risk-based methods seek to remove bias from the analysis enabling a more transparent debate as to which management options are preferred and which features of the flood system contribute most to the risk.

  The concepts of risk also implicitly include the notion of uncertainty and seek to recognise uncertainty where it exists and propagate it through the analysis. This enables effort to be directed towards those uncertainties that contribute to the rationale doubt in choosing between one course of action and another.

- **Consider dynamic nature**
  Risk-based approaches recognise that the flooding system is dynamic in space and time, as well as being dependent on changes within or external to the system (Figure 3.6). It is, therefore, often necessary to predict how risk might change in the future in response to:
  - climate change (natural variability, greenhouse-gas induced climate change etc);
  - land-use changes (urban infrastructures, area of rural landscape, impermeable surface, drains etc);
  - socio-economic and political (legislative) drivers and pressures including FRM policies and processes;
  - the likely damage should a flood occur and how this alters future flooding and erosion rates;
  - changes in the protection afforded by defences (deterioration, maintenance, new works, adaptations);
  - changes in the effectiveness of non-structural measures (e.g. improved flood warning, development control, regulations and response).

  As risk changes, our management response also changes. The dynamic nature of this must be integrated in the risk assessment and so accommodated in the planning or operational decisions.

3.3.2 How does RASP support risk-based thinking?

A summary of the generic risk analysis process and the characteristic curves used in the first generation RASP methods is given in Figures 3.7 and 3.8. This will need to be extended to support the more holistic management proposed in Making Space for Water.

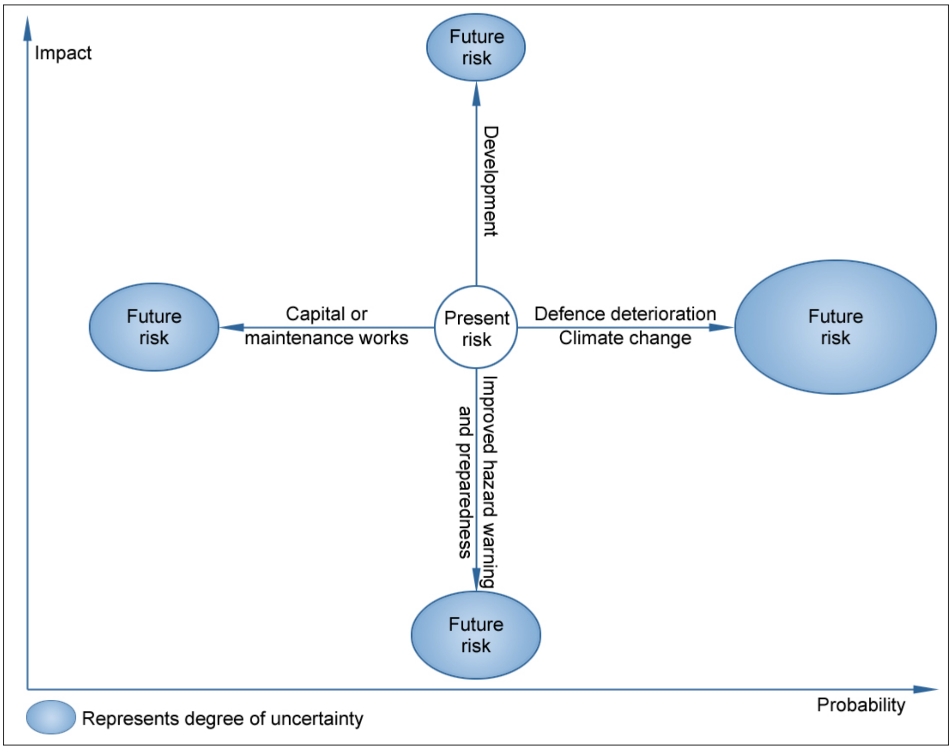


Figure 3.6: The dynamics of risk (Environment Agency, 2002)

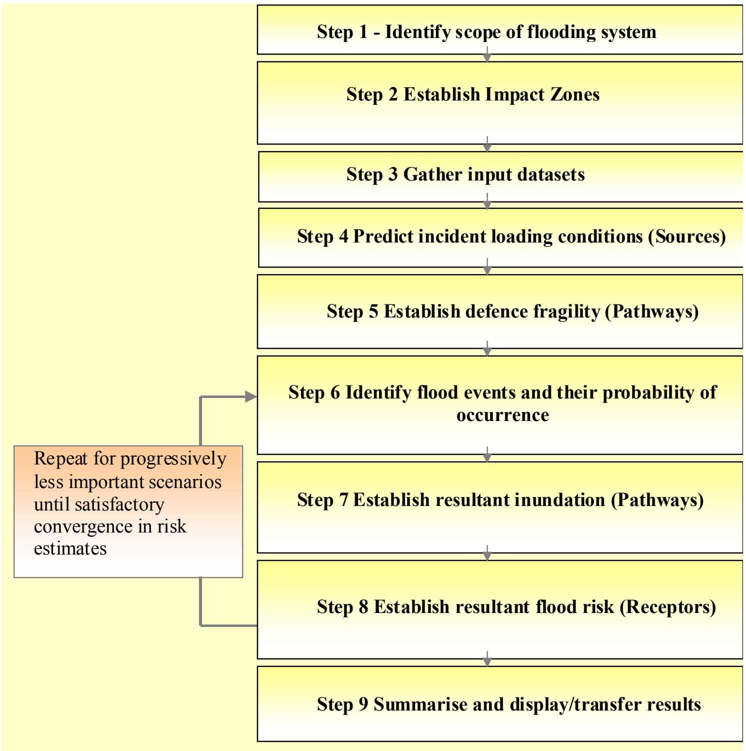


Figure 3.7: A generic risk analysis process used in the first generation RASP methods (adapted from Environment Agency, 2004)

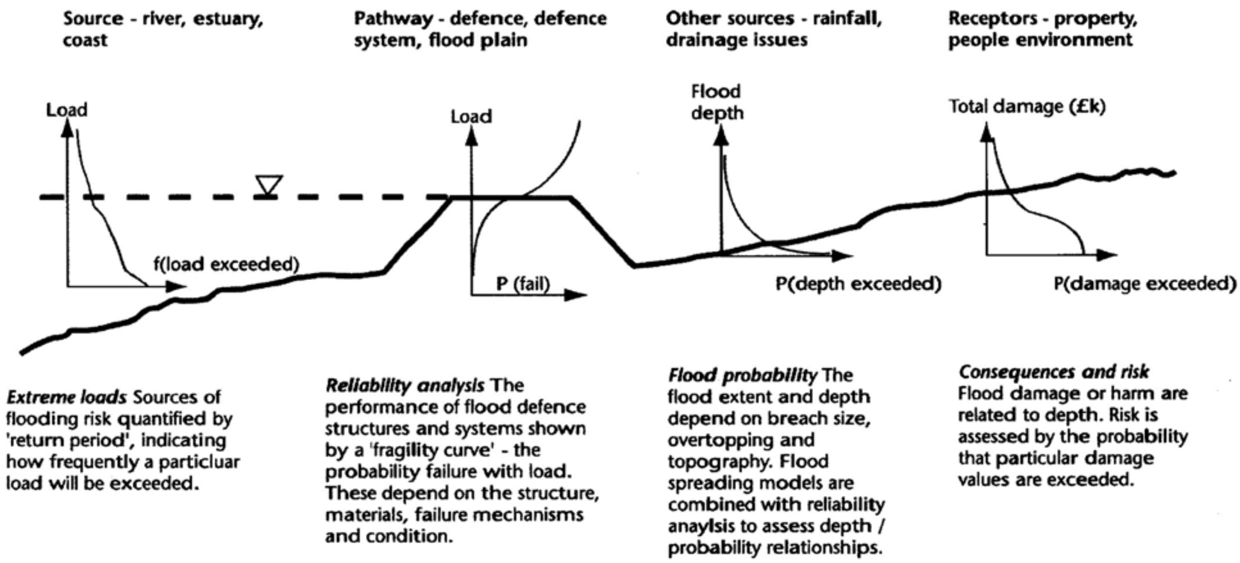


Figure 3.8: Generic risk characteristic curves used in the first generation RASP methods (adapted from Sayers *et al.*, 2002)

RASP methods can support the goal of risk-based assessment by:

- explicitly quantifying both the probability and consequence of flooding;
- being explicit about the associated uncertainty and providing a basis for targeting data collection and modelling to reduce uncertainty;
- enabling risk to be attributed to individual assets to help focus effort towards areas of greatest benefit.

3.4 A hierarchical analysis framework

The third core principle of the RASP methods requires a hierarchical approach to decision-making. The benefits of this approach and the nature of the support provided by RASP are discussed below.

3.4.1 Why adopt a hierarchical approach?

Flood risk management strategy and delivery is based on a hierarchical structure – with regional and local scale planning nested within national policies and targets. It is clear that a comprehensive risk-modelling framework should reflect this in order to provide information appropriate to each planning and delivery level at the right amount of detail.

Consistency between the chosen system model abstractions at any given level within the hierarchy is not assured, due to differences in modelling methods and assumptions, data quality, and computational scales. This is a potential source of error (when transferring information between levels), and uncertainty or misunderstanding (when the different levels appear to be giving different results). Flood risk management requires a clear and consistent understanding of the risk and so the methods need to be developed such that they interrelate in a consistent manner. As we develop improved systems, risk assessments at a local level, using data from appropriate sources such as local inspections/surveys and LiDAR data, those risk assessments will probably be of high quality and should become the definitive versions. Data management and modelling techniques will then be required to ensure that the data is available and used, suitably synthesised, at the 'higher' tiers. This suggests that a priority should be to develop the tools that give a good local picture of risk – and to allow users to view this at whatever resolution is appropriate for their purposes. An example of how this might work is that PAMS will provide local detail of flood risk for each asset system and this data could then be 'interrogated' by national tools to make a national assessment of risk. This is not a trivial exercise. The models used for this purpose will need to ensure that individual systems are not considered in isolation: they may need to reflect the influence of other systems in the catchment/basin for example.

It will be some years before we have complete coverage of the floodplain at such a high level of detail – and that may not, in any case, be appropriate in lower risk areas. In the meantime there will be a major role for national and regional models such as NaFRA and MDSF to provide risk assessments. If we do promote a 'top down' flow of information we will need to consider how the data will be used at the local scales. It is important to avoid over-interpreting the accuracy of the data and also important to manage the inevitable discrepancies in data between levels. Even the simple process of re-scaling flood probability results to different spatial units causes discrepancies. Clear guidance on the up and down scaling of information will therefore be an important intermediary step.

3.4.2 Uncertainty

Assessment and management of risk provides the decision-maker with an opportunity to consider the importance of the uncertainty in the context of the specific decision being made. The aim should be to assess and process uncertainties and to reduce uncertainty so that decisions are robust.

There are several types of uncertainty, each of which needs to be dealt with appropriately. Probabilistic methods are widely used and do represent many of the main causes of uncertainty – but other methods such as interval analysis, scenario and sensitivity testing and Bayesian methods all have their uses (Sayers and Meadowcroft, 2005). The Flood Risk Management Research Consortium (FRMRC) is developing tools for uncertainty analysis. These include guidance on selecting appropriate methods, depending on the source of the uncertainty, data available etc, and this should help dialogue between decision-makers and modellers.

A major challenge is that of model uncertainty – the degree to which the model matches reality. Evaluating the quality of a model is an important and challenging issue. There are areas where model evaluation is quite possible – for example, in real-time forecasting or checking inundation predictions against photo/post-event mapping. There are other areas – such as prediction of extremes – where it is much more difficult. We suggest that it is fundamental to the development of RASP that evaluation studies be carried out wherever possible, in order to understand and communicate the influence of both model and data uncertainties. Consideration should be given to reducing, where possible, bias and uncertainty by 'conditioning' the models to the available data. At present this is not part of the modelling process but it should be investigated.

A hierarchical approach enables available data to be utilised according to the level of decision, and the uncertainty reported to the decision-maker. If the decision warrants further targeted data collection to reduce uncertainty this can be clearly justified and commissioned. The application of risk assessment methods serves to highlight shortcomings in data which should/could be rectified and there is great potential here to marry the modelling enterprise with data collection strategies.

3.4.3 How is a hierarchical approach supported by RASP?

The notion of a hierarchical approach is fundamental to the way in which the existing RASP methods have been developed (the hierarchy used in the first generation RASP methods is given in Table 3.1). For example:

- **Use of expert judgement** – RASP does not require the application of complex models *per se*, but it does force expert judgement to be quantified and assumptions justified.
- **The use of common information and explicit recognition of uncertainty** – The RASP framework enables the accuracy of the data to be progressively refined and the level of the analysis modified to reflect the decision in-hand. It is not the formal recognition of this hierarchy that is innovative, however, but rather the progressive nature of analysis from one RASP level of analysis to the next. For example, a fragility curve describing the likelihood of failure for a given load can be based on either judgement or a detailed reliability model. In either case, the information is presented in a similar format (Figure 3.9).

- **The use of available data** – Any hierarchy of tools should be able to share information and data. The concept within RASP is that all data is provided from, and returned to, nationally accessed databases, primarily the NFCDD (National Flood and Coastal Defence Database) but also linked databases such as the NPD (National Property Dataset). Given the common data formats utilised within RASP, decision support tools based on RASP should be able to share information and data.

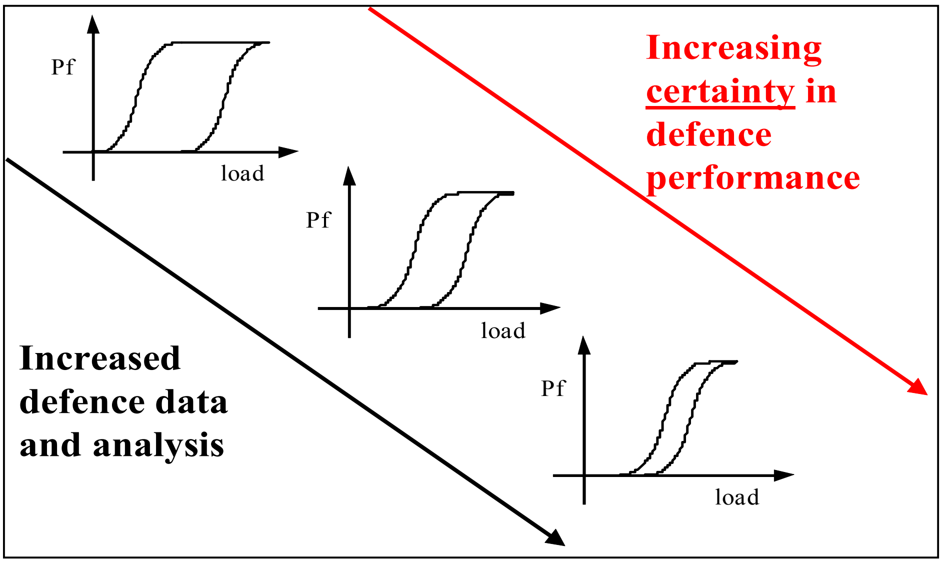


Figure 3.9: An example of the progressive nature of a hierarchical analysis (Sayers and Meadowcroft, 2005)

Table 3.1: RASP hierarchy used in the first generation RASP methods (adapted from Environment Agency, 2004)

Analysis complexity	Governing Assumptions
Higher level methods	The higher level methods are typically characterised by three assumptions: ***Independence between source and pathway variables*** – i.e. the interaction between the floodplain and the river is ignored within the model but handled through the derivation of appropriate input variables. ***Dependence of asset loading*** – i.e. each asset within a given defence system is assumed to experience the same severity of load simultaneously (although the absolute loading condition, for example the wave height and water level, will vary defence by defence). ***Independence of asset strength*** – i.e. the behaviour of an individual asset or asset element does not influence another.
Intermediate level methods	The intermediate level methods typically attempt to relax one or more of the higher level assumptions: ***Relaxed assumptions and implications*** ***Dependence between source and pathway variables*** – i.e. the driving loading conditions are provided at the boundary of the river/coastal system and the river channels are considered as part of the pathway. This enables the feedback between the river and floodplain, and any associated relief/increase of asset loading to be directly incorporated. ***Independence of asset loading*** – i.e. this enables the dependences in loading between defences defending the same flood area to be considered. ***Dependence of asset strength*** – this enables the behaviour of one asset or asset element to influence another. For example a breach in one location may weaken the neighbouring defence; or the modified management of a river channel may influence the downstream assets due to scour or increased loading; the construction of a groyne in one location may modify beach levels elsewhere.
Detailed level methods	The detail level methods typically attempt to relax one or more of the higher level assumptions using more rigorous methods than those typically employed within the intermediate level methods.

Notes:
1. Within the continuum of analysis provided by RASP each individual model may be more or less detailed. For example, a fragility curve describing the reliability of an individual asset may be based on a very detailed reliability analysis of a single asset (involving the gathering of specific data and use of complex process models, e.g. as used in the analysis of the Thames Barrier) or a more simplified method based on more basic descriptors of the asset available nationally (e.g. overall condition grade and crest level as used in NaFRA 2005).
2. The assumption of dependency of loading is considered a robust assumption for the policy appraisal of flooding driven by fluvial and coastal sources. It would, however, need to be relaxed to enable the inclusion of additional sources (pluvial, groundwater, sewer flooding).
3. Relaxing the assumption of independence of strength increases the computational complexity markedly, requiring second influences on asset strength to be included. It is likely to be sometime before such a capability exists.

The integration of the loading distributions with the fragility curves (and onward to flood risk) is handled through discretisation of the loading variable into *m* bands. The probability of any particular flooding scenario (defence system state and loading event) is therefore given, for the i^{th} loading band, by (using the example in (1)):

$$\Pr\{\overline{d_1} \cap d_2 \cap \overline{d_3}.....\overline{d_n}\} = \left[\Pr\left(L \geq \frac{l_i + l_{i+1}}{2}\right) - \Pr\left(\geq \frac{l_i + l_{i-1}}{2}\right)\right] \Pr\{\overline{d_1} \mid l_i\} \Pr\{d_2 \mid l_i\} \Pr\{\overline{d_3}\}.....\Pr\{\overline{d_n}\} \quad (2)$$

The flood depth or velocity with an impact zone associated with each flooding scenario (e.g. equation 2) is then calculated. Firstly, the volume of water discharged into the floodplain through each defence section is calculated. For defences that have failed, a breach width and invert level is calculated as a function of the load (Hall *et al.* (2003)). The distribution and depth of the flood water within the floodplain area is then calculated using an appropriate flood spreading model. The flood depth (or velocity) for each flooding scenario within the Impact Zone is thus determined. The calculation of economic damages, for example, is then straightforward based on knowledge of the type, floor area and number of properties within each impact zone (Flood Hazard Research Centre – Multi-coloured Manual).

4 Current RASP methods and tools

This chapter reviews the status and range of applications of RASP that are currently in use, or under development. In particular, we review the status of system models and their use at various stages of FRM planning and delivery. The main risk-based tools are summarised in a series of tables covering national policy planning, strategy planning and asset management planning. In each case, the most appropriate tools are discussed, with particular reference to how they can best be implemented and the areas that users would like to see improved. The chapter emphasises the 'overlapping' nature of these tools – in particular the use of common modules and methods where appropriate.

This chapter is largely concerned with application of current tools. Chapter 5 goes on to discuss possible future developments, including improvements to existing tools and development of new ones to fill gaps.

4.1 Present status and application

Throughout the past 20 years risk assessment and decision support tools have been provided to users to help make sense of the complexity of the decisions being made. However, until recently these have often failed to meet expectations for a variety of reasons. Perhaps the most important lesson history teaches us is that to be successful risk assessment and decision support tools must focus on a given problem from the perspective of the decision-maker and do so in a way that ensures the process will be consistent from one application to another. This implies the need for a common risk-based framework that compiles a range of tools to meet the specific needs of a given decision-making process. The RASP concept, method, framework and related tools are catering for this need. By operating within an integrated framework, the risk assessment and decision support tools are able to utilise common datasets (prompting continued improvement) and share common analysis modules where possible and practical.

Each of the FRM plans described in Figure 2.4, requires risk assessment and decision support. For risk and decisions of a similar nature it maybe possible to provide a single risk assessment and decision support tool. These practical enactments of the RASP methods are now being built upon or developed as operational tools, designed specifically for use by the Environment Agency, including specific tools to support national policy, strategy planning and asset management. As shown in Figure 4.1, three RASP (risk assessment and decision support) tools are currently being developed that support a sub-set of the planning process; namely:

- National policy planning through NaFRA (National Flood Risk Assessment).
- Strategic planning through MDSF2 (Modelling and Decision Support Framework).
- Delivery planning for asset systems management through PAMS (Performance-based Asset Management System).

The utility of the first generation RASP methods has already been demonstrated, at a national scale (as part of NaFRA 2002, 2004, 2005 and 2006 – see for example Figure 4.2a); at a catchment scale (e.g. as part of the Thames Estuary 2100 project, see Figures 4.2b and 4.2c); and at more local scales in the context of Strategic Flood Risk Assessments in Kinmel Bay, North Wales, and ongoing studies in Boston, Lincolnshire.

The first Modelling and Decision Support Framework (MDSF1), offering a relatively simple picture of risk, has been widely taken up in the delivery of Catchment Flood Management

Plans (CFMPs) and Shoreline Management Plans (SMPs). The next generation Modelling and Decision Support Framework (MDSF2) will build on current understanding of the processes, RASP methodology and capabilities, to develop improved decision support systems in the separate areas of fluvial, estuarial and coastal flood modelling. These tailored tools will provide practitioners and decision-makers with a consistent and effective framework for risk assessment and decision support.

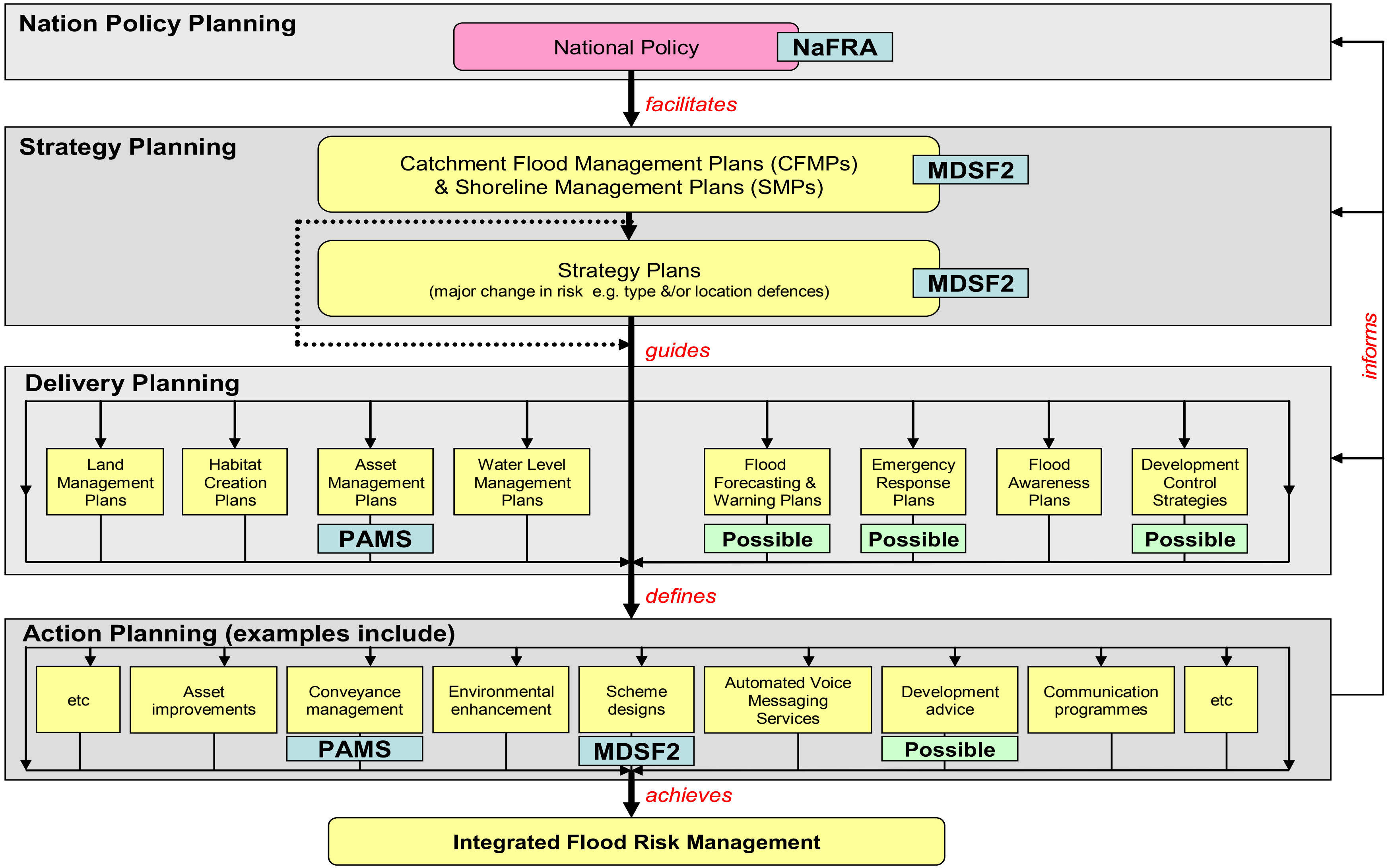


Figure 4.1: Existing and ongoing developments of RASP-based tools overlaying the planning hierarchy of the Environment Agency. (This chart is under development – this version was current at the time of writing but is subject to change)

Figure 4.2a: Example output from NaFRA 2006 for a combined fluvial/coastal catchment on the east coast

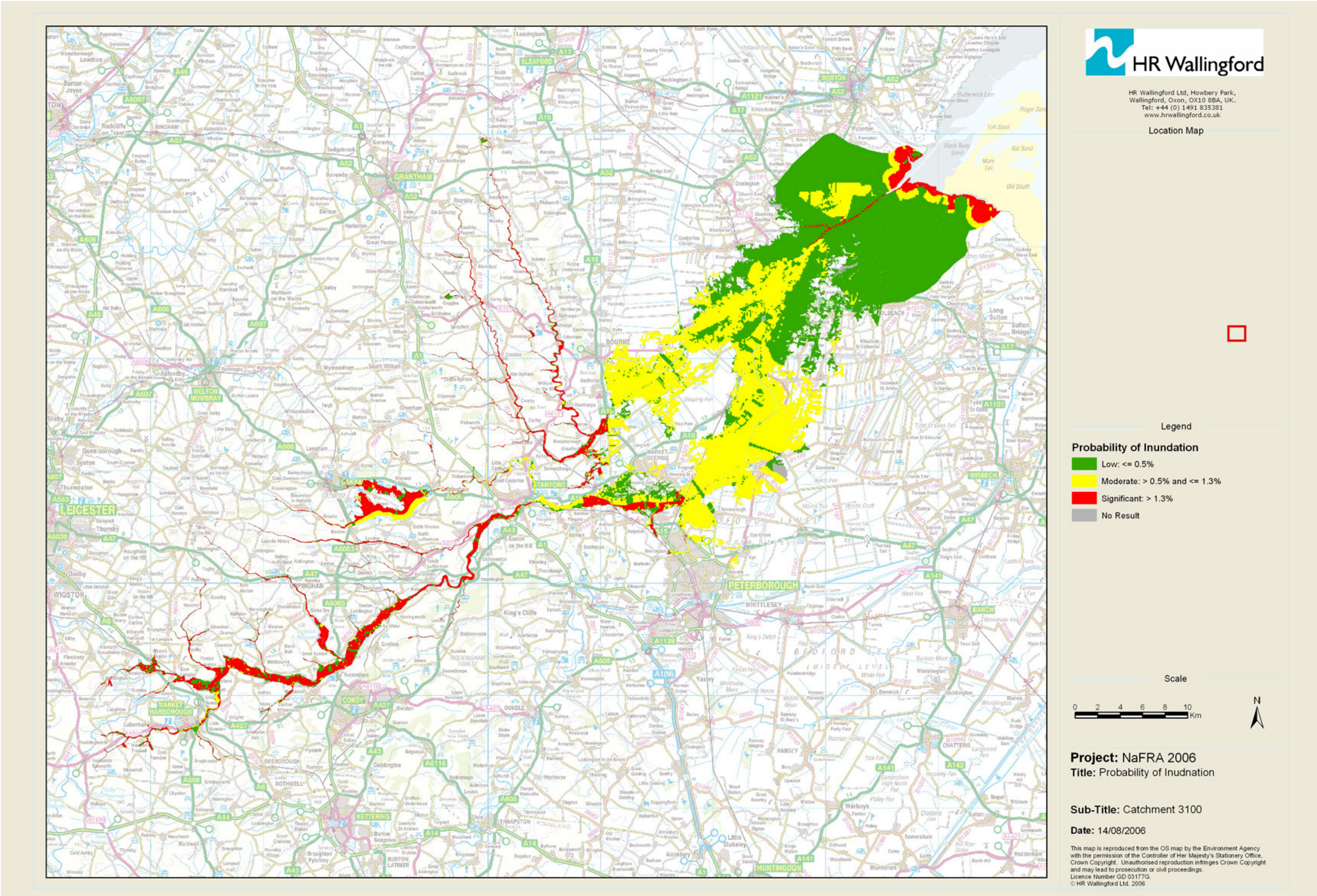


Figure 4.2b: Example output from the estuary-wide RASP-based system model established for the Environment Agency Thames Estuary 2100 (TE 2100) team (present-day flood probability across the whole tidal Thames)

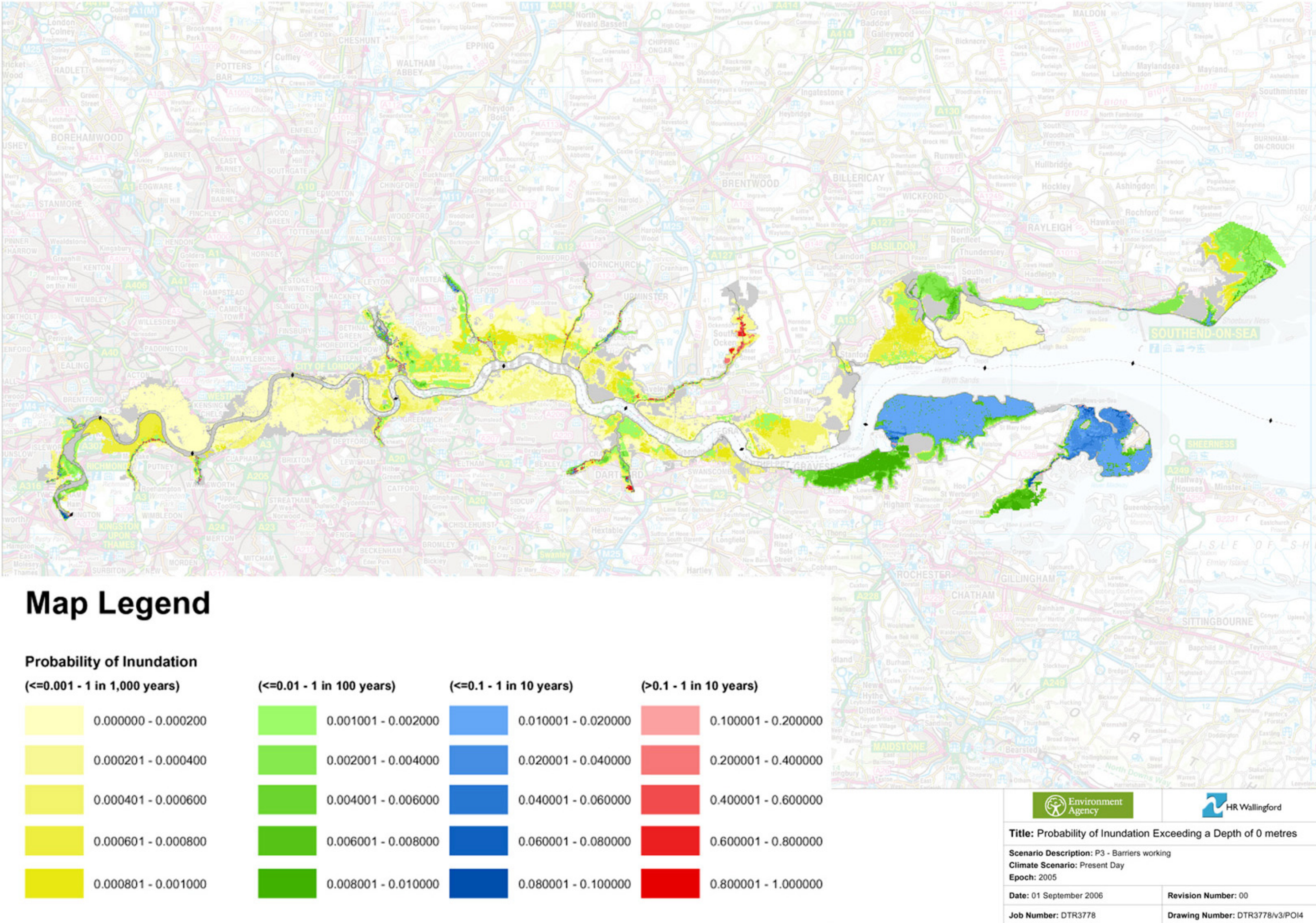
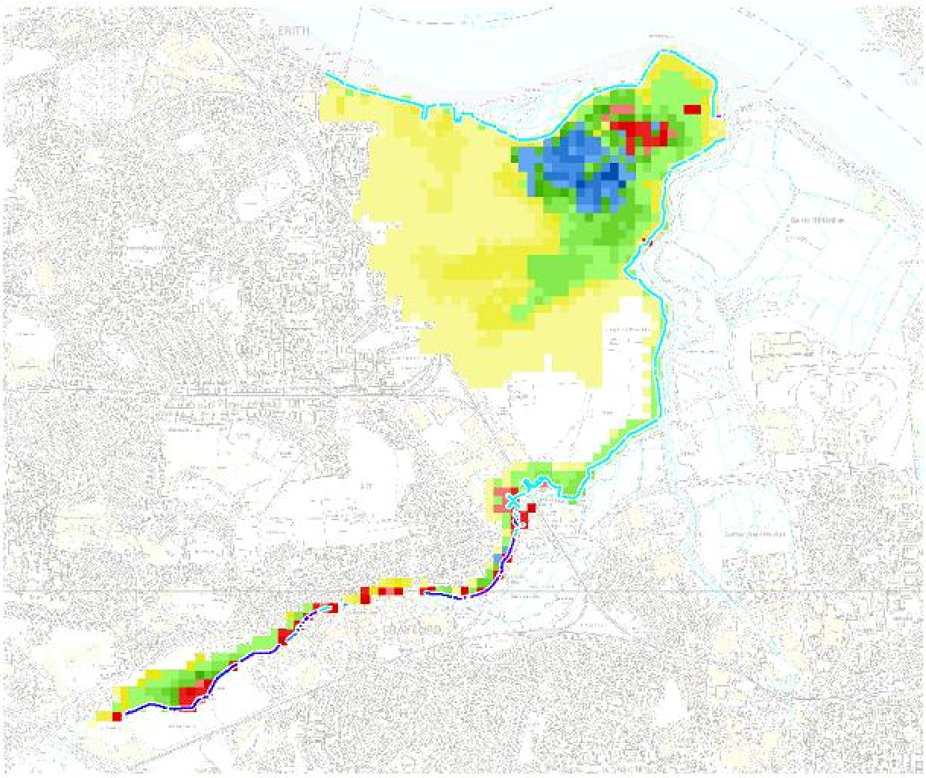


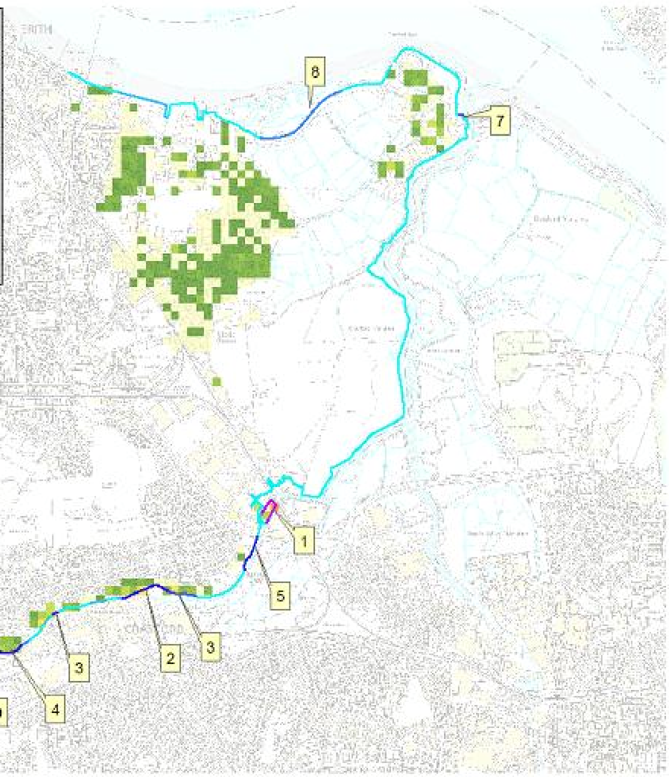
Figure 4.2c: Example output from the estuary-wide RASP-based system model established for the Environment Agency TE 2100 team (an extract for Crayfordness)

Probability of Inundation (P1 2005)



Expected Annual Damage (P1 - 2005)

Ranked Top 10 Defences	Defence contribution to EAD (£)
1	£286,999
2	£33,433
3	£28,257
4	£22,559
5	£18,817
6	£17,201
7	£12,371
8	£8,510
9	£4,500
10	£4,361
Number of Defences in Flood Area	103
Percent %	94.21%
Total Flood Area Risk (£)	£463,885



4.2 Current planning tools and interrelations

More details regarding the existing planning tools or the planning tools under development are given in Tables 4.1, 4.2 and 4.3 under the following headings:

- Decision level and role
- Background
- Supporting tool
- Supporting analysis method/engine
- Programme of development
- Decision need
- How will the model be used?
- Resolution of analysis (spatial and temporal)
- Areas of improvements?

The following tables are business process oriented, and tools such as MDSF2 appear in several tables as they can be reused to support more than one business process.

National policy planning, strategic planning, or delivery and action planning are all using the same RASP concept and methods developed for system planning (Figures 4.3, 4.4 and 4.5). The RASP framework provides the general flood risk analysis engine linking decision-specific tools (e.g. MDSF2, NaFRA and PAMS – Figure 4.3). Although the RASP framework/methods have a significant role in all of these tools, each tool also includes a number of non-RASP aspects (including process guidance and tailored pre- and post-processing tools and software interfaces). The use of RASP as a common risk analysis framework ensures that the best available information and software can be efficiently integrated for a range of different applications, in a way that enables the bottom-up and top-down flow of information.

Figure 4.3: RASP will support multiple planning levels

Table 4.1: National Policy Planning – NaFRA (National Flood Risk Assessment)

Decision level and role
National Policy Planning – Provides the policy framework within which all other decisions are made and actions taken. In particular, national policies influence the nature of the management activities promoted at more detailed levels and the relative priority of different risks.
Decision need
To provide effective policy guidance, decision-makers need to understand present-day risks and how these may change in the future. They also need an ability to explore, at a suitable scale, the effects of major drivers on flood risk, and, in broad terms, the effectiveness and efficiency of a wide range of FRM measures and associated uncertainties. This understanding can also be used to monitor the change in risk on a national basis, for target-setting and long-term investment planning.
Background
The NaFRA tool was first established using the RASP so-called higher level method in 2002. Since then the methods and data employed have improved year on year with applications in 2004, 2005 and 2006.
Supporting tool
The NaFRA tool is necessarily constructed to use datasets available at a national scale; and is dependent on the NFCDD as well as other datasets. The NaFRA tools have been used, and continue to be used, to provide a country-wide 'snapshot' of flood probability and risk at a common resolution throughout the fluvial and tidal floodplain in England and Wales.
How will the model be used?
At present the NaFRA is run nationally by a limited number of consultants. This will probably remain the case going forward. NaFRA utilises nationally available datasets. Therefore, it will be important that the Environment Agency and all of its consultants understand the needs of NaFRA and *buy into* the process and resultant products. This will promote improved data gathering and feedback between Strategy and Activity Plans and the national assessment of risk. It will be important that NaFRA can be run sufficiently efficiently to support national-scale scenario planning and policy appraisal (e.g. in support of the Comprehensive Spending Review, and long-term horizon scanning projects similar to Foresight).
Supporting analysis engine
RASP higher level methods – with embedded physical process models where required. The NaFRA tool is a self-contained single 'model' that estimates source terms (currently defined as in river water levels and joint coastal wave and water level conditions), assesses defence performance, spreads flood water on floodplains and calculates the risk metrics of choice (based on those with existing relationships between flood depth and damage).

Table 4.1: National Policy Planning – NaFRA (National Flood Risk Assessment) – *continued*

Resolution of analysis
Spatial – Although the outputs are currently provided on 100 m x 100 m (max.) grid to the internet, the fundamental spatial resolution of the NaFRA tool is only restricted by the available resolution of the floodplain and the minimum asset length in terms of the defences. ***Temporal*** **–** Snapshot based.
Programme of development
The NaFRA development is currently in year 2 of an approved 5 year business plan. It is expected that the RASP methodology used to support NaFRA will stabilise in 2008/09. After 2008/09 it is hoped that inter-year comparisons of changes in flood risk will increasingly reflect the 'true' influence of the flood management interventions rather than improvements in data and/or analysis methods.
In what areas would users like to see improvements?
1) Improved reliability of the risk assessment Given the requirement for national coverage, improvements to the system at any of the nine steps in the RASP methodology (Figure 3.7) or the underlying data would be useful. Perhaps the most significant request is to maximise the use of the available digital elevation model (DEM) data. This would demand a significant, but possible, modification of the flood spreading algorithms embedded within the NaFRA tool (as tested under the TE 2100 project). An improved ability to undertake scenario analysis and policy appraisal will become a priority as the NaFRA tool is increasingly used to support initiatives such as the National Assessment of Defence Needs and Costs (so-called NADNAC) and Foresight-type analysis. Longer-term enhancements will include a move away from the snapshot analysis and include other flood sources and pathways – such as pluvial and groundwater sources as well as urban drainage infrastructure. **2) Improved policy appraisal capabilities** In 2003 the NaFRA tool was further developed to support NADNAC through the inclusion of a simplified whole-life costing approach. NADNAC is likely to remain a key activity supported by NaFRA into the future.

Table 4.2: Strategy Planning – MDSF2 (see also Table 4.3 for other applications)

Decision level and role
Strategic planning – Strategic planning seeks to translate policy to practice for a specific location (e.g. catchment or community) and should broadly, but robustly, establish the appropriate mix of interventions and responses required and the broad timescale for implementation.
Decision need
Strategists have similar needs to national policy makers, but demand more certainty to ensure that planning decisions are robust. In particular, strategy planning needs to be based on an exploration of the effectiveness and efficiency of a wide range of strategic alternatives (regulation, protection, flood warning etc) and the preferred combination of interventions and actions, to define a costed programme of activities. As with national policy making, good strategy plans are robust to future change (climate and socio-economic etc) and reflect the need for sustainable solutions, Not all strategies demand the same level of detail and hence the tools provided must be flexible in terms of the detail they provide. MDSF2 will be specifically designed to support the development of integrated strategies and hence must be flexible and capable of distinguishing the performance of different options and operating at a range of levels of detail (reflecting the demands of a particular situation). The original MDSF is already in use by consultants for a range of applications down to scheme level, and MDSF2 will be directed at the same users.
Background
MDSF2 supports the specific option appraisal process implicit in CFMPs/SMPs and strategies. Therefore MDSF2, as MDSF1, will be capable of exploring the trade-off between engineering solutions, flood warning and social resilience, regulation etc and exploring various future scenarios. It is not possible to prescribe any level of detail that is universally appropriate to CFMPs/SMPs, strategies or schemes. MDSF2 is therefore independent of the level of detail applied – with the defining issue relating to the nature of the decision and its sensitivity to uncertainty.
Supporting tool
MDSF2 – Modelling and Decision Support Framework 2 (building upon MDSF1). MDSF2 aims to support the development of: • Catchment Flood Management Plans. CFMPs will in inform river basin management plans. • Shoreline Management Plans and Coastal Defence Strategy Plans. • Estuary Strategy Plans. MDSF2 may also be used in other applications as it is scale independent. For example, it may be used as a strategy planning tool as well as for the implementation of strategies at a more local level. It is in effect a 'continuum tool' in that the data and external models may be updated at any stage. (It should be noted that the RASP method of integration cannot be altered without substantial changes.)

Table 4.2: Strategy planning – MDSF2 – *continued*

How will the model be used?
It is envisaged that the Environment Agency will continue to use consultants for the development of Strategy Plans. This implies that the approach to the description of the sources and pathways need not be prescribed (as within NaFRA). This will enable consultants to continue to use their particular modelling approaches to represent river hydraulics for example, yet within the common analysis framework provided by RASP. This will also allow the Environment Agency to continue to use the latest models available to the market place. Receptor data and analysis methods, as well as the principles of the appraisal and decision-making (e.g. the discount rates and decision-rules) are, however, likely to be prescribed (reflecting the direct prescription of these methods by the Environment Agency and Defra through the Project Appraisal Guidance (PAG) series and other guidance).
Supporting analysis engine
RASP analysis engines (combining the higher level and intermediate level analysis approaches)
Resolution of analysis
Spatial* –** Unrestricted in terms of the resolution of the floodplain and by minimum asset length in terms of the defences. ***Temporal – Snapshot.
Programme for development
MDSF2 is currently being developed within the MAR Theme and is due to deliver a beta version for testing in 2008.
In what areas would users like to see improvements?
1) Improved reliability of analysis MDSF2 is currently restricted to the consideration of linear structures. This will need to be extended to include point structures to provide effective consideration of the asset systems. Future versions (MDSF3 and beyond) will need to extend the definition of sources and pathways to provide a more holistic support to the aims of Making Space for Water. The first generation tool MDSF2 is likely to be a snapshot-based model with interpolation between simulations. Further development will be required to support the more dynamic system analysis required by Making Space for Water. **2) Improved policy appraisal support** As improved capabilities to quantify the impact of flooding (particularly social and environmental impacts) are developed these will need to be incorporated. MDSF provides a natural home for the provision of the assessment of broader multi-criteria and sustainability measures as they are developed and introduced into the industry.

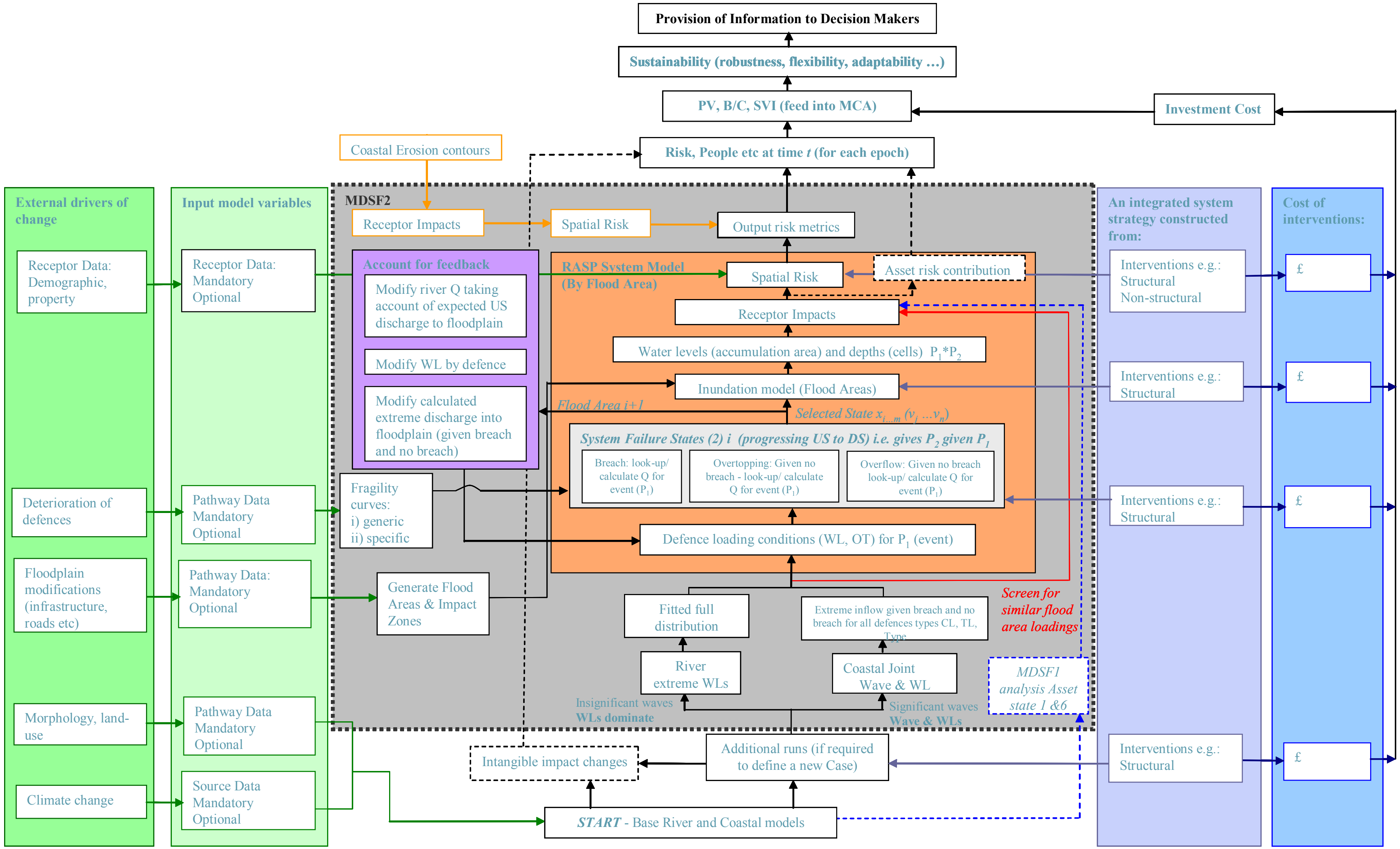


Figure 4.4: The emerging high level modularity of the MDSF2 (the RASP analysis engine is shown in orange in the above diagram – associated outline data flows are also included in Appendix 2)

Table 4.3: Asset Management Planning – MDSF2 and PAMS

Decision level and role
Delivery and Action Plans – Asset managers take their lead from national policies and the specific asset management policies or measures set out within the higher level Strategy Plans (where they exist). Where these policies include management or improvement of existing assets, asset managers seek to ensure that these are implemented in the most efficient and effective manner.
Decision need
Asset managers seek to manage infrastructure based on a whole-life philosophy that includes the maintenance and eventual removal/replacement of an asset. This necessitates consideration of a long-term (>50–100 years) appraisal period within the strategy planning process. Asset managers are then tasked with determining the most efficient and effective programme of interventions within the context of either medium-term (3–5 years) and/or long-term (5–10 years) planning horizons. To do this decision-makers need to understand the contribution each asset makes to risk and the influence a particular intervention has on risk reduction and its associated cost.
Background
PAMS provides and overarching tool and associated process to help asset managers to deliver Asset System Management Plans. In the context of a hierarchy of decisions, Asset System Management Plans support all other plans by providing bottom-up support. For example, it has always been envisaged that asset management provides the base data on the assets, their location, condition, geometry and fragility to other planning processes within the Environment Agency and outside. This is done through the data collected as part of the 'day job' and as part of the development of Asset System Management Plans.
Supporting tool
Given the varying nature of Asset System Management Plans (from simple decisions to more complex) two different tools will be used to provide decision support. • **MDSF2** – for complex hydraulic situations where the asset intervention is likely to materially change the hydraulic regime. • **PAMS** – for more routine decisions where the asset intervention affords a moderate change to the hydraulic regime (e.g. crest level raising, strengthening or conveyance management). Note: Both tools will of course be supported by more specific tools such as the conveyance estimation system (CES) and other hydraulic and process models. The information determined through these models will then be used within PAMS and MDSF2.
How will the model be used?
MDSF2 – *complex situations* – likely to be used by consultants engaged by the National Capital Programme Management Services (NCPMS) teams to support the development of new schemes and more major asset management strategies. It may be necessary to provide additional modules and a tailored graphical user interface (GUI). **PAMS** – *more routine asset management* – the PAMS tool will be utilised where the hydraulic regime remains largely unaltered. This will enable the asset manager to develop an effective programme of interventions within the context of either medium-term (3–5 years) and/or long-term (5–10, 10–30 years) planning horizons. PAMS is being constructed with the goal of providing a tool for use directly by Environment Agency staff. As shown in Figure 4.5, the PAMS tool contains five components, each of which will be of relevance to different parts of the Environment Agency. However, the RASP systems analysis tool component is being primarily designed for use by staff from the Environment Agency's Flood Risk Asset Management and Enforcement teams. This is in clear contrast to the proposed usage of MDSF2, where the Environment Agency's consultants are the intended users.

Table 4.3 Asset Management Planning – MDSF2 and PAMS – *continued*

Supporting analysis method
MDSF2 – described above. **PAMS** – The analysis engine within PAMS will be based on a combination of the RASP higher level and intermediate level analysis. However, the data on the likely performance of the assets (in particular the resolution of the fragility curves and structural geometry and conditions) is expected to be significantly better than developed in either policy or strategic planning activities. Given that PAMS is likely to be run within the Environment Agency, the RASP engine will include fully embedded models and linkages to national datasets, including the value-added results from previous strategies and NaFRA studies.
Resolution of analysis
Spatial – Unrestricted in terms of the resolution of the floodplain and by minimum asset length in terms of the defences. ***Temporal*** – Snapshot based.
Programme of development
PAMS is currently being developed within the Sustainable Asset Management (SAM) Theme. The current phase, which completes in 2008, will not produce a fully functioning software tool. This is simply too complex given the associated changes to NFCDD as well as the business processes that will be necessary before PAMS can be fully implemented. Instead, Phase 2 focuses on taking a measured step forward towards PAMS and providing the key methodologies. Full implementation into software is expected under Phase 3 in 2010/11.
In what areas would users like to see improvements?
1) Improved reliability of analysis • Improved supporting data – Asset data quality will be particularly important, both in terms of location, line and level and structural condition. • Improved understanding of asset performance – The main focus of interest for PAMS users is in asset performance of linear defences, point assets (barriers, gates and pumps) and watercourse vegetation and morphology. Improved understanding of how all of these assets perform will be required as the PAMS methods are developed and rolled out. • Improved understanding of how assets change in time – understanding the deterioration of assets will be an important component of developing optimal intervention strategies. **2) Improved option appraisal support** • Risk attribution – Attribution of flood risk to particular defences provides a powerful tool to support the option selection process. • Uncertainty exploration – Uncertainty propagation methods are likely to be increasingly important to determine where key uncertainties lie and how to reduce/manage them. **3) Design support** • Reliability based design – Once the location and required performance specification of an asset has been determined the detailed design of an improvement or maintenance activity can proceed. In keeping with the philosophy of the overall risk-based approach, a reliability based design would enable a move away from safety factors (such as freeboard) to a more explicit recognition of the uncertainties in the design process. It would also enable the designer to identify those aspects of the design that are important in terms of achieving the required performance specification (and where effort should be focused) and those that have limited influence. Note: At this stage the focus would be on the performance of the asset design under load – to achieve a given annual failure probability and overtopping rate – and hence it would not be necessary to reconsider receptor terms and risk.

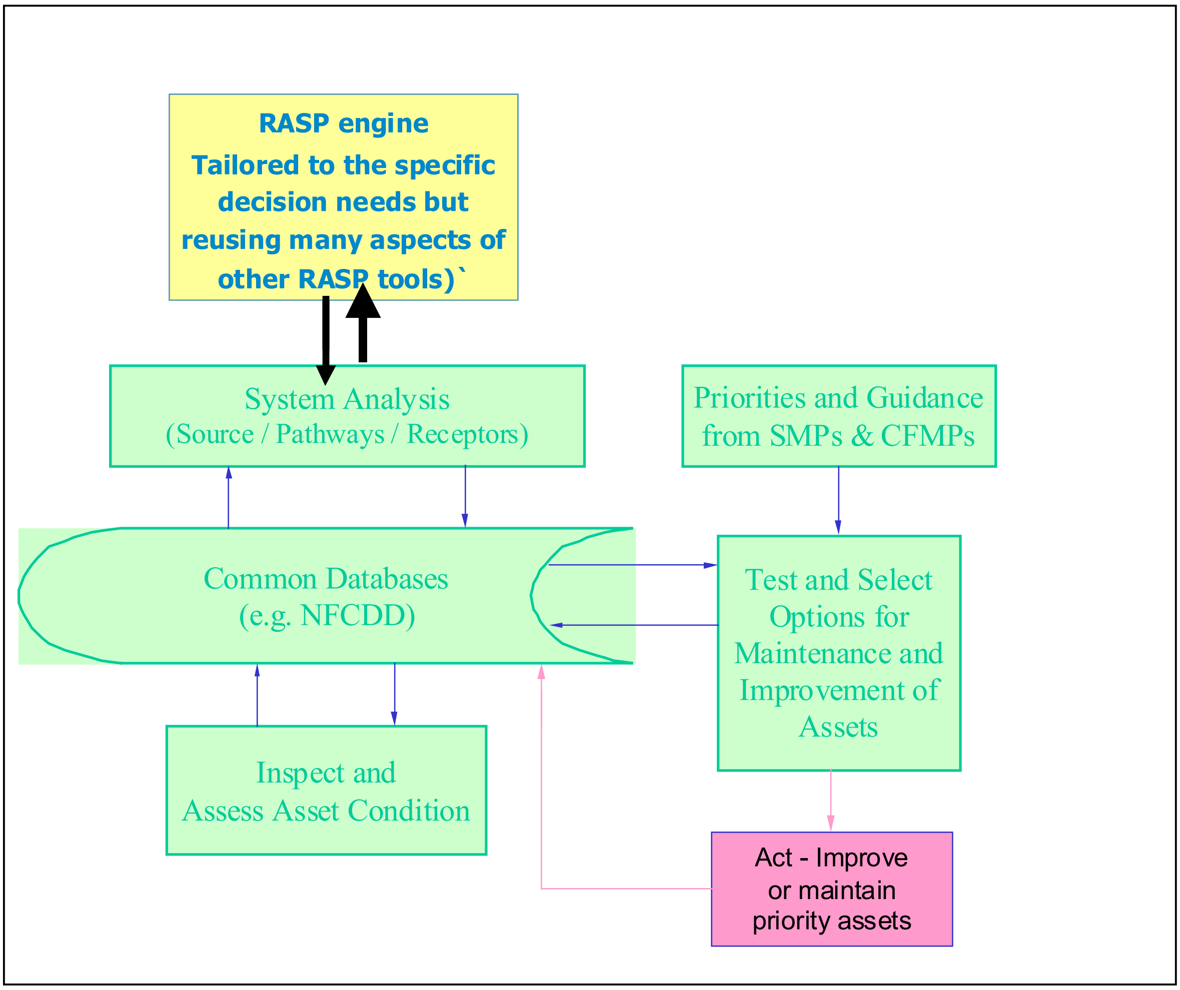


Figure 4.5: RASP provides the system analysis component of the PAMS tool

The RASP engine is a key component of the proposed PAMS tool and provides the 'system analysis' as noted in Figure 4.5*.* Associated outline data flows are also included in Appendix 1.

4.3 Recently completed relevant R&D projects

A number of projects have been recently completed that provide direction to the further development of RASP and specific aspects of the risk analysis. The most important of these projects are noted below:

- Risk Assessment for New Property Development – FD2320
- Risk Assessment for Flood Incident Management – SC050028
- Risk to People – FD2321)
- Environmental Consequence – Environment Agency's E-Pol R&F Project.

5 Recommendations for further development of RASP method

The previous chapter was largely concerned with the application of current tools. This chapter goes on to discuss the issues, and possible future developments related to FRM functions, including improvements to existing tools and development of new ones to fill gaps. Detailed recommendations for specific research projects and programmes in terms of source, pathways receptors, generic system analysis frameworks, development of decision-specific tools, generic guidance, and development of the support IT systems and software tools are presented in
Chapter 6.

5.1 The policy process and science programme context

The development of the next generation of RASP methods will be shaped by the changing policy context. This includes, for example:

- ***The Water Framework Directive*** – This demands greater integration between the management of flooding risk and the ecological function of the system, which will bring new challenges.

- ***The Floods Directive*** – This reinforces the need for a hierarchical approach for flood risk assessment and management.

- ***FRM Modelling Strategy*** – The current vision (seen by the authors) provides limited impact on the RASP methods. However, a broader modelling strategy is likely to shape the way in which data is shared and reused and the way in which the approach to modelling proceeds.

- ***Making Space for Water*** – This is set to have the most significant impact on the RASP methods. In particular, MSfW demands a more holistic view of the sources of flooding and options available to manage the associated flood risk. The current S-P-R approach will need to be extended to reflect the driving metrological conditions and a broader definition of the pathways of flooding.

- ***Science Programme*** – It is also recognised that research methods are developing at a significant pace. The MAR thematic programme and other thematic programmes within the joint Defra/Environment Agency FCERM R&D programme, TE 2100, Flood*site*, the Flood Risk Management Research Consortium (FRMRC) and other research programmes provide an 'innovation-push' to the ongoing development of the RASP methods. For example, continued advances in areas such as scenario analysis and continuous simulation will soon demand a modification to the way in which risks are analysed and managed (see for example the FRACAS project recently funded through the NERC FREE programme).

5.2 An overview of the user requirements

Based on consultations undertaken within the original RASP research, previous projects and during this project (including workshops held in June and September 2006) the key user requirements for the future RASP tools can be summarised as follows:

- To promote the use and reuse of data across all relevant business functions.
- To present evidence of flood risk in a useful and meaningful manner.
- To provide a transparent and challengeable assessment of risk.
- To promote a consistent approach to risk assessment across all relevant functions.

5.2.1 What business process issues need to be considered?

Successful implementation of new decision support tools into the Environment Agency will require a number of business processes to be addressed. In the past little attention has been given to these issues and hence attempts to implement new tools have often failed. The key lessons learnt from past experiences are listed below.

- **Business objective led development and implementation.** The need for each new tool and the requirements for each tool must be assessed in conjunction with user groups. This will avoid ineffective and inadequate tools searching for a purpose.

- **Involvement of all the expected users in development and implementation.** This requires a clear understanding of all the different types of user, including the Environment Agency staff at the relevant levels, local authority staff, internal drainage board staff and their advisers. This scoping report has focused mainly on the Environment Agency, but wider involvement of relevant organisations will be required as each specific tool is developed.

- **Gradual introduction** of tools to enable the business processes to:
    - adjust to new tools;
    - deal with issues (e.g. data) that could affect the usefulness of their outputs;
    - have a realistic programme and resource allocation for implementation;
    - have training and learning feedback processes.

- **Achieving user acceptance by demonstrable added value to risk management decisions**. The RASP methodology should only be used in areas where it provides added value to relevant users.

- **Ability to validate the results,** to ensure that results are of high quality and assure users that these tools are providing the best available information on risk. This is a very high priority since without being able to 'prove' the accuracy, or provide a means of developing user confidence in the outputs, the tools will always struggle to be accepted.

5.2.2 What tool selection issues need to be considered?

Successful implementation will require clarity in the selection and use of tools. The lessons learnt from past experiences relating to the tool-dominated issues are:

- **Appropriate level of analytical rigour for the level/type of decision being taken**. Tools to support particular business decisions must be plausible for these decisions and not be used inappropriately for other decisions.

- **Appropriate level of input data quality for decision-making**. The required level of data quality must be understood. The need to improve data quality or completeness to obtain useful results could result in a clear driver for data improvements.

- **Transparent methodologies within each tool**. 'Black-box' modules should only be used within tools where the user has no real need to understand that process. In all other cases the end-user must be given some understanding of the processes involved in the methodology and the relevance of the outputs to decisions they take.

- **Appropriate level of flexibility in each tool**. The tools need to be flexible enough to account for the requirements of different users. Users should be able to employ the tools to their maximum benefit, and not be forced to a rigid framework that may not provide the best value.

- **Good interface**. Significant effort should be made to ensure that the interaction of users with the systems is as seamless and friendly as possible. This will require user involvement at all stages of development, testing and delivery.

- **Flexibility**. To enable easy updating of tools as technology or the knowledge base improves.

5.3 Other risk modelling tools

Section 2.2 discussed, in broad terms, the main types of model available for assessing risk in flood systems. These types of model form the basis for a range of tools that have been developed to support the decision-making process.

Table 5.1 provides a summary of tools available throughout Europe and further afield. A large number of tools have been developed in recent years, as part of a trend towards evidence-based methods for assessing and managing risk. Many of the tools take advantage of new technology, data sources and modelling methods to provide new information on risks, tailored to a range of decision-makers.

Table 5.1: Overview of risk assessment and decision support systems (DSSs) - planning kit

(evaluated as part of Floodsite – Task 18)

DSS acronym	Full name
DESIMA	Decision Support for Integrated Coastal Zone Management
DSS-Havel	Decision Support System for the Havel River
Elbe-DSS	Decision Support System for the Elbe River
EUROTAS	European River Flood Occurrence and Total Risk Assessment System
FLIWAS	Flood Information and Warning System
FLUMAGIS	Flusseinzugsgebietsmanagement mit GIS (GIS-based River Basin Management)
Flood Ranger	
HzG	Hochwasserinformationssystem zur Gefahrenabwehr (Flood Information System for Hazard Defence)
INFORM 2.0/.DSS	Integrated Floodplain Response Model
IRMA-Sponge DSS Large Rivers	Large rivers: interactive flood management and landscape planning in river systems
IVB-DOS	Integrale Verkenning Benedenrivieren – Discussie Ondersteunend Systeem (Integrated Exploration of the Lower Rivers – Discussion Supporting System)
MDSF	Modelling and Decision Support Framework
NaFRA	National Flood Risk Assessment
PAMS	Performance-based Asset Management System
RISK	Risikoinformationssystem Küste (Risk Information System Coast)
STORM Rhine	Simulation Tool for River Management of the Rhine
WRBM-DSS	Werra River Basin Management DSS

Note*:* RASP – Risk Assessment for System Planning is deliberately missed from the above table. This reflects RASP status as an analysis engine rather than a decision support tool.

Table 5.1 provides welcome evidence of significant advances but it is notable that model solutions have tended to develop to suit each country's policies and operational structures. However, the models share common technical features, and have similarities in the way they represent many processes. There is great potential to learn from others' experience. Projects such as Flood*site* are ideally suited to exchange this type of information and experience. Lessons learnt from other countries should be fully documented and taken into account in any future Environment Agency and Defra developments, to ensure these build on a wide range of international experience.

5.4 Summary of costs and benefits of adopting a RASP-based family of tools

There will be inevitable ‘start-up’ costs in developing and implementing new risk assessment tools. These include the cost of additional research (where required), the development of software (and associated testing etc) and the support of implementation within the business processes. The benefits of adopting a coherent approach across the Environment Agency's business areas will, however, be significant. No attempt has been made here to quantify these benefits but they are likely to include:

- improved data sharing (supporting the collect once use many times principle);
- better integration of understanding and decisions action across all functions;
- a reduced need for repeat work and duplicate or contradictory investment;

- the facilitation of a progressive move away from the more deterministic methods currently used towards the application of probabilistic methods;
- a better understanding, inside and outside the Environment Agency, of the need for both 'top-down' and 'bottom-up' approaches to support the delivery of an integrated approach to flood risk management (e.g. the role of asset inspection of existing systems and how such data informs policy choices and policy choices modify the approach to asset management);
- the provision of unbiased data on risk and its attribution between stakeholders.

The development of a 'family' of risk-based tools offers a number of software and implementation advantages. These include:

- **Ease of updating** – in many cases a single update to one software module can be easily incorporated into all tools, avoiding the need for multiple updates.

- **Ease of training and dissemination** – users across the Environment Agency and elsewhere will increasingly become familiar with the RASP philosophy and hence the analysis methods. Where staff move from one function to another the underpinning models will be immediately familiar.

- **Ease of central support and CIS[3] approval for new tools.**

Subject to a more detailed business case, it is clear that the development of a coherent set of decision support tools that utilise the RASP risk assessment engine could yield significant cost savings, both in terms of the development and implementation costs and also through increased operation efficiency.

Many of the above benefits are based on development of a set of standard tools delivered to consultants and Environment Agency offices. This centralised approach will bring consistency and will ensure that technical standards are met, but there are possible drawbacks. In particular, this approach could suppress innovation. If the approach is not flexible enough to deal with local circumstances and systems, this may inhibit acceptance. There is also a risk of being 'locked in' to a small number of suppliers.

On the other hand a looser, less centralised approach, could facilitate more flexible tools, possibly better adapted to local circumstances but at the expense of standardisation – clearly there would be a risk of multiple, divergent risk models, each known to only a few specialised users, which would be undesirable.

The optimal solution probably incorporates the best elements of both these approaches. The challenge is to develop and implement a standardised family of risk models while allowing appropriate tailoring to local circumstances – being flexible enough to deal with a wide range of decisions, processes and constraints.

Any developments will of course need to conform to the Environment Agency's modelling strategy, which is likely to consider these issues in more detail.

[3] Environment Agency's Central Information System

5.5 Using support tools to promote the use and reuse of data

In 2002 Defra and the Environment Agency introduced a National Flood and Coastal Defence Database (NFCDD) which for the first time provided, in a digital database, an inventory of flood defence structures, their location, geometry and condition. Coupled with sister databases, on the so-called I:Drive and those held at Agencys offices in Twerton, the concept of shared data is starting to become a reality. Although significant effort continues to be required in order to bring this about in practice, the development of the RASP family of decision support tools will be fundamental to achieving the goal of shared and evolving data. Equally, an ability to access shared and evolving data is fundamental to the success of the proposed tools. For example, all of the proposed tools will utilise information on river location and defences (i.e. at a single defence length scale or finer) and receptors (i.e. at a single house scale). They will also all use floodplain levels. The concept of common datasets supporting all the decision-specific tools is shown in Figure 5.1.

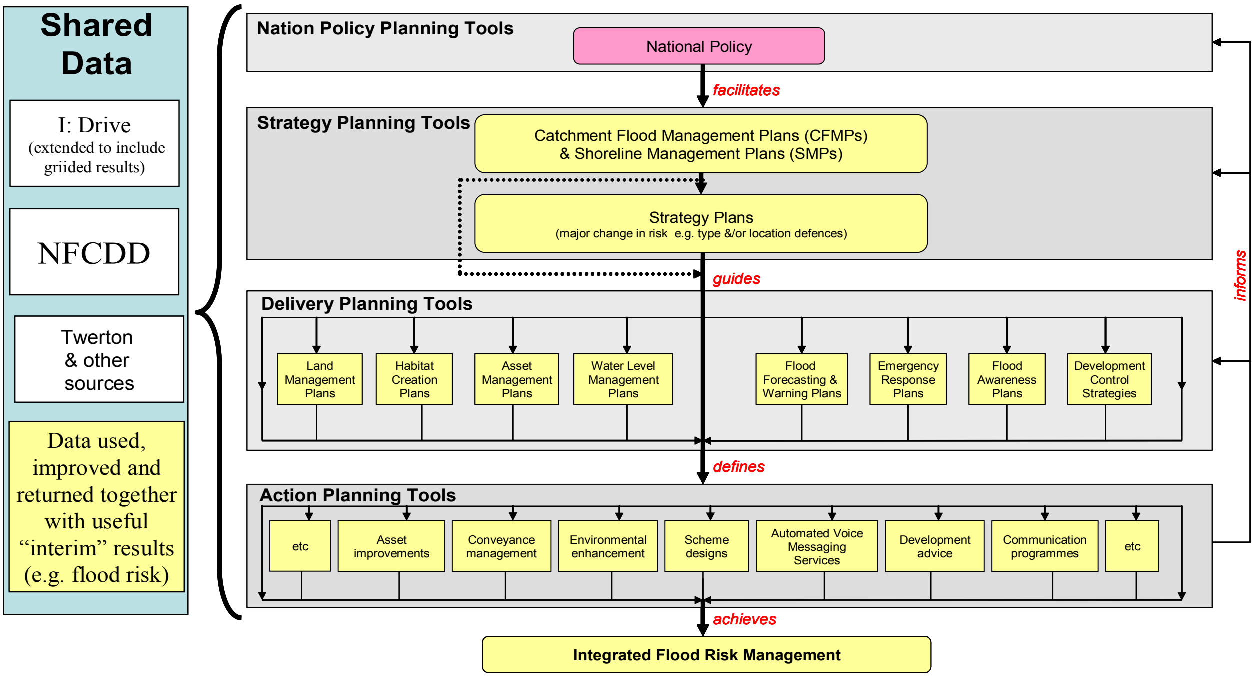


Figure 5.1: Common shared data is used to support all tools and planning decisions. (This chart is under development – the version shown was current at the time of writing but is subject to change)

For the relationship between common tools and shared data to be successful, the RASP tools must not only take data from the common datasets but also pass useful results back. For example, all RASP tools could be capable of passing back information on:

- the overall contribution that each defence makes to flood risk (£EAD);
- the contribution that an asset makes to flood risk, assuming overtopping only (i.e. the probability of structural failure is ignored);
- the contribution that an asset makes to flood risk, assuming breach only (i.e. only the probability of structural failure is included);
- the probability of flooding within a given impact zone within the floodplain associated with

various flood depths, velocities and durations;
- the expected annual damages associated with a given impact zone (for a range of receptors – people and property etc);
- intermediate results, e.g. flood depth grids from CFMPs/SMPs etc for use in development control and elsewhere.

The exchange between RASP-based tools and shared databases has always been a central theme in the development of the RASP approach and remains so. The practicality of achieving this level of data sharing will be a significant challenge and raises serious questions of model and data management. It will be important that the key providers of the base data utilise RASP (and the data they collect) to inform their own decisions. For example maximising the use and reuse of data collected and used within Flood Risk Asset Systems Management will be vital if assessments of flood risk within other plans are to improve. Without a connection between the 'day job', the databases and the decision support systems it is unlikely that the data will evolve effectively or efficiently.

5.6 Future needs and opportunities to utilise existing RASP methods

Based on the preceding discussions with FRM Policy, Processes, Operation and Science Managers, the requirements for range of risk-based decision support tools are summarised in Table 5.2. In addition to those discussed in the previous chapter, the RASP-based methods could be used to support a broader range of plans that make up flood risk management (Figure 4.1). Although not all of the remaining planning decisions require a detailed understanding of flood probability, a RASP-based tool could usefully be used to provide effective support to the following planning processes, where the relevant tools are outlined in Tables 5.3 and 5.4:

- **Development control strategies and plans** (Table 5.3) – This would be classed as a delivery plan and could relatively easily be supported using a tailored version of the RASP components of PAMS and, for more complex situations, MDSF2.
- **Emergency response planning** (Table 5.4) – The development of emergency response plans often relies on a detailed understanding of the hydraulic processes and hence is likely to require the flexibility afforded by an MDSF2-type tool. This would enable Flood Incident Management teams to develop pre-event plans that recognise the chance of defences breaching and the associated heightened risk to life.
- **Capital programme management** – Activities under the capital programme management can either be classed as strategic planning or asset management/improvement (i.e. scheme design). The NCPMS teams would therefore utilise the tools approach to the particular project at hand (i.e. if undertaking a CFMP, MDSF2 would be used).

There is also need for further development of the generic risk characteristic curves, similar to those used in the first generation RASP methods and the *multi-coloured manual* (describing the likely damage for a given flood depth) (Figure 5.2). In particular, further development is required for the curves to characterise:
- the effectiveness of rural and urban pathways (e.g. flood plans, storage) that modify the flood characteristic;
- effectiveness of non-structural measures that minimise the risk;
- mortality and environmental consequence for different flood characteristics.

Table 5.2: Requirement for improvement or development of risk-based decision-support tools for planning

Phase	User-oriented FRM tool/interface	R&D resp.	FRM engine
Policy Planning	**NaFRA –** National Flood Risk Assessment	MAR SPD	Continued advancement of the RASP HLM+. In particular this will include improvement to enable what-if testing and scenario planning (similar to that completed for the Foresight project) and improved capability in flood spreading to enable the direct use of DEM data. This is likely to share modules on receptors and the calculation of impacts given flooding with strategy planning tools (e.g. MDSF2). The ongoing development of the NaFRA tool is currently being scoped through the NaFRA 2007 development project.
Strategy Planning	**MDSF2** – Modelling and Decision Support Framework 2	MAR/ SAM/ ICM/ SPD	Continued development of the RASP techniques to provide the basic probabilistic analysis engine capable of interfacing with external, user-selected, hydraulic models. MDSF2 will build upon MDSF1 and available RASP tools (e.g. NaFRA and those under development in TE 2100 and Flood*site* – Task 18) and reuse, where possible, existing code and interfaces. MDSF2 will be a fully functioning open interface and will be independent of scale of application. It will be appropriate for supporting the development of broad-scale regional strategies to local scheme development. It will have the capability to include both structural and non-structural responses and distinguish the relative merits of both. **Note:** MDSF2 is also likely to be used to support more complex decisions – where calibrated local models of sources and pathways are required and typically associated with the engagement of a consultant – related to: • asset system management • development control and regulation • flood incident management – pre-event planning • scheme design and capital project development.
Asset System Management Planning (including revenue and capital works)	**MDSF2** – Modelling and Decision Support Framework 2 **PAMS** – Performance-based Asset Management System (and supporting tools such as the CES/AES etc) **In the longer term:** reliability based design tools	MAR/ SAM	***Complex intervention schemes*** – The NCPMS has a significant role in the development of new schemes. Typically these will be outlined within the Strategy Plan; however, it may be necessary to explore the design of the scheme further through feasibility studies. It will be appropriate to reuse the MDSF2 tool for these more complex situations (where the cost is significant or the hydraulic or environmental regime is significantly altered by the proposed intervention). ***More routine asset management*** – Where the hydraulic regime remains largely unaltered, asset management teams within the Environment Agency will be able to utilise the RASP analysis embedded within the PAMS tool. This will enable the asset manager to explore the impact of different asset management interventions on flood risk and determine the most effective programme of interventions within the context of either medium-term (3–5 years) and/or long-term (5–10, 10–30 year) planning horizons. In the longer term ***reliability based design*** may be used to support a move away from safety factors (such as freeboard) to a more explicit recognition of the uncertainties in the design process. It would also enable the designer to identify those aspects of the design that are important in terms of achieving the required performance specification (and where effort should be focused) and those that have limited influence. Note: At this stage the focus of the decision would be on the performance of the asset under load in order to achieve a given performance target (e.g. annual failure probability and overtopping rate). It would not therefore be necessary to reconsider receptor terms and risk.

Table 5.2: Requirement for improvement or development of risk-based decision-support tools for planning – *continued*

Phase	User-oriented FRM tool/interface	R&D resp.	FRM engine
Development Control and Regulation	**MDSF2** – Modelling and Decision Support Framework 2 **Bespoke risk-based** development control and regulation – similar in concept to NaFRA and PAMS	SAM	***Strategic planning of development policies and responses*** – At a regional and national scale there is a need to understand the potential changes in risk associated with the potential development pressures (e.g. possible implications of the Barker Report in terms of increased flood risk) and to develop possible development control policies and processes. This type of policy appraisal would be supported by a NaFRA/PAMS-type tool based on the higher level RASP methods but with a tailored interface and/or additional analysis modules. ***Complex proposals (to be explored by the developer)*** – In association with a complex proposal (where the cost is significant or the proposed development may significantly alter the hydraulic regime) MDSF2 could be provided to the developer and their consultants to enable an exploration of the change in risk. ***Less complex cases and policy exploration*** – Development control planning could utilise an equivalent to the PAMS tool provided for asset management to respond to relatively straightforward local application and/or explore development strategy on a wider scale. This will enable development control staff to respond easily and consistently to planning requests. ***Note:*** The influence on flood risk of developments outside the fluvial and coastal floodplains would not be dealt with easily by these tools and new methods to extend their capability would be required.
Flood Incident Planning and Management	**MDSF2** – Modelling and Decision Support Framework 2 **In the longer term:** real-time risk-based management support – possibly operated within the National Flood Forecasting System (NFFS)	MAR/ ICM	***Pre-event (MDSF2)*** – The general-purpose tool being developed to support strategic planning would enable the effectiveness and efficiency of any given detection, forecasting, warning and response system to be explored in the planning phase. As noted above, MDSF2 will be capable of including external models and hence can be constructed at any level of detail with any level of physical representation. MDSF2 could therefore enable specific flood pathways of flood waters to be identified, temporary barriers tested and evacuation routes explored. To do so, however, the basic science of flood event management would need to be improved. ***During an event (bespoke real-time support)*** – Although it is outside the scope of this report to consider real-time tools, if such a tool were to be developed it would need to operate within the NFFS and provide real-time forecasts of flood risk and marshal real-time observations on flooding. ***Note:*** The above tools only consider the provision of information regarding the likely flood risks. Flood event management is as much about communication between the emergency forces as it is about understanding the probability and consequences that might occur. Additional tools to support better communication flow during events need to be considered alongside the RASP-based tools.
Capital Programme Planning	No additional tool to those noted above.	MAR/ SAM	Activities under the capital programme management can either be classed as strategic planning or asset management/improvement (i.e. scheme design). The NCPMS teams would therefore utilise the tools approach to the particular project at hand. Therefore, if undertaking a CFMP, MDSF2 would be used. For the completion of a detailed scheme design a combination of MDSF2 and the future reliability based design tool discussed under the Asset Management heading would be used.

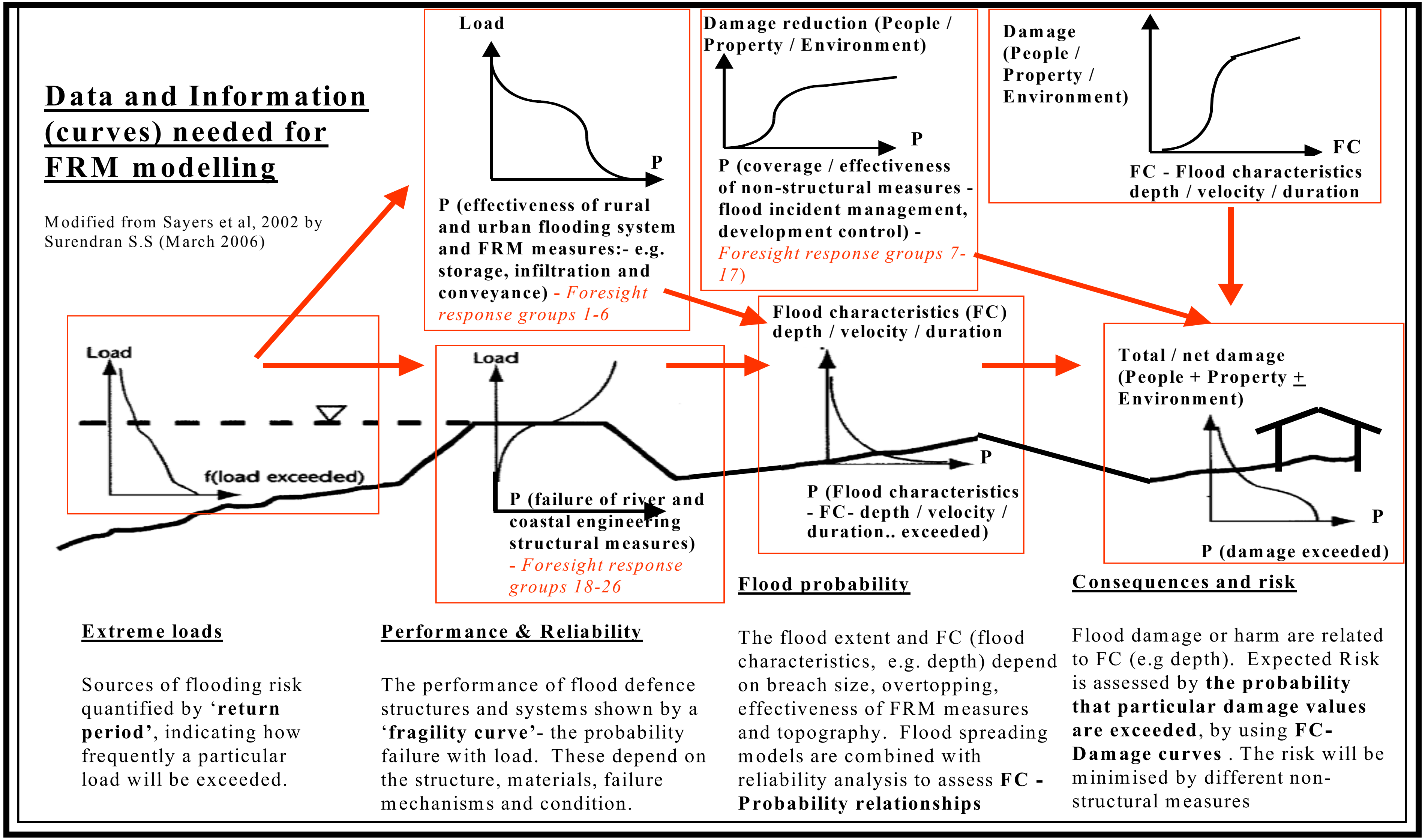


Figure 5.2: Data and information (generic risk characteristic curves) needed for FRM system planning models (after Surendran 2006)

Table 5.3: Development control and regulation – supported by MDSF2 and a tailored decision-specific tool

Decision level and role
Delivery and Action Plans – Regulation and development control represents the most direct route to managing future flood risk through the removal of receptors or improvements to their resilience to flooding (see for example Evans *et al.*, 2006). Development control takes place both in the context of strategic planning, where development controls policies are explored and development areas discussed, and in the context of delivery planning, where individual planning applications are considered and suggestions made.
Decision need
Development control and regulation teams need to understand risk to and from specific development plans whether those plans are regional spatial strategies, local development frameworks or individual planning applications. As such, development control officers have a range of needs, from those which are similar to regional strategy makers down to those which require a level of accuracy similar to that required by asset managers. In particular development control staff require evidence on the: • change in risk within the boundaries of the new development – taking account of receptor exposure and vulnerability and of protection afforded by existing and any new defences constructed as a part of the development; • change in risk outside the boundaries of the new development – taking account of changed run-off, the protection afforded by downstream defences and receptor exposure and vulnerability. ***Providing bottom-up support to higher level plans*** Regulation and development control should be able to add value in improving or validating receptor datasets, including, for example, locally detailed topographic surveys and property threshold levels and detailed information on development proposals established through Strategic Flood Risk Assessments (SFRAs) or more detailed Flood Risk Assessments (FRAs).
Supporting tool
Two tools have been identified as potentially useful in supporting development control and regulation decisions, namely: ***MDSF2*** – *In support of more complex SFRAs and FRAs* – it may be appropriate to engage a consultant to establish specific source, pathway and receptor models and (perhaps) gather specific data. In these situations it will be appropriate to reuse the MDSF2, perhaps with a tailored GUI and associated business process support. ***Bespoke tool (similar to PAMS in concept)*** – In more straightforward cases, access to existing national data on flood risk generated through previous national appraisals or Strategy Plans together with an ability to explore changes in risk through simple what-if perturbations to the input data, could provide sufficiently reliable insights in support of a response to a particular development plan or planning application. The bespoke tool would utilise the majority of the NaFRA and/or PAMS modules with an additional decision-specific interface (e.g. allowing the quantified tests outlined in PPS25 and TAN 15 to be directly applied).

Table 5.3: Development control and regulation – supported by MDSF2 and a tailored decision-specific tool – continued

How will the model be used?

MDSF2 – This will be constructed to enable its use by either the Environment Agency's consultants or the consultants to the development promoter. This adds few additional requirements to the MDSF2 tool; however, it will be important to ensure additional guidance is provided to enable those less familiar with flood risk to make proper use of the tool.

Bespoke tool – The tool would be constructed to be available for use directly by Environment Agency regulation staff at their desktop. The tool would draw from national databases held by the Environment Agency and enable what-if testing. This would enable Environment Agency staff to delineate proposed developments and take a view on their impact on flood risk.

Supporting analysis method

MDSF2 – See above.

Bespoke tool – A combination of the RASP higher and intermediate level methods is likely to provide sufficiently reliable results for developments proposed within the floodplain.

Resolution of analysis

Spatial – Unrestricted in terms of the resolution of the floodplain and by minimum asset length in terms of the defences.

Temporal – Snapshot of any given system state.

In what areas would users like to see improvements?

Beyond those improvements already discussed in connection with strategic planning and asset management, the decision support provided will need to be enhanced in a number of areas if it is to be effective in aiding development control and regulation teams. Improvements might include:

- Receptor data quality. This will be particularly important, in terms of location, line and level and structural condition.
- Location and performance of defences, as regulators may wish to require developers to improve defences as part of granting permission. As a result, for the same reason as for PAMS, attribution of flood risk to particular defences via the flood spreading calculation will also be important.
- Groundwater and pluvial flooding and the performance of proposed mitigation.
- Water resources and water provision.
- Extension of the tools to explicitly consider flooding/and change flood generation outside the fluvial/coastal floodplain.

Table 5.4: Flood incident planning and management – MDSF2 and (possibly) bespoke tools within NFFS

Decision level and role
Delivery and Action Plans – Effective warning and incident response is likely to play an increasingly important role in future flood risk management. Within incident management there are two key aspects that require decision support: ***Pre-event management planning*** – here Strategy Plans should provide the flood incident manager with guidance as to the likely role of flood event management, as part of an integrated FRM response within any given area. The emergency planning process, however, will require considerably more detail including evacuation planning, options for real-time control of flood levels during a major event (e.g. preferential flooding of upstream areas, perhaps including pre-engineered weak links, or fuse plugs). ***During/near event forecasting and response*** – the NFFS currently provides the modelling shell. Adoption of risk-based methods within the context of real-time decision-making is likely to be an important area of development in the future. However, this report considers only the pre-event planning processes and real-time management is not considered further here.
Decision need
Pre-event planning – Within the context of pre-event planning the Flood Incident Management teams will seek to maximise the efficiency and effectiveness of the flood forecasting and warning process as part of an integrated response to flood risk. This process is already happening (e.g. the TE 2100 team is already using the old MDSF1 to identify critical receptor hot-spots to aid the development of incident response plans at a strategy planning levels). To adopt a more risk-based method to event planning, including the probabilistic assessment of defence failure for example, could provide a significant improvement in the development of emergency plans. However, providing such support is not a straightforward extension to any of the existing tools. ***Real-time forecasting and response*** – At present flood warnings are largely issued solely on the basis of predictions of source events. As recommended within the Best Practice Guidance on Coastal Flood Forecasting (Environment Agency Project SC050069) it would be possible and desirable to move towards the prediction of ***flood risk*** in areas where the risk is high. In *high risk* areas flood incident managers need to understand, given a range of specific real-time forecast weather (source) scenarios, the probable flooding that will arise (taking account of associated breaching and overtopping of defences) and the consequences in terms of damage and losses. Such an understanding would better inform decisions regarding the issuing of flood warnings, erection of temporary and demountable defences and recommendations to emergency services for evacuations. With such tools it would be possible to support a better understanding of the flood risk associated with a given forecast storm-tide or fluvial flood warnings for: • when to erect demountable defences; • where to intervene in order to attempt to prevent failure of critical defences; • identifying the most at-risk receptor populations for warning and evacuation purposes. ***Providing bottom-up support to higher level plans*** Flood Incident Management teams often have significant and useful information that can be fed back into the other activities including information on flood evacuation routes and the likely performance of flood warning, detailed address point information and housing types. This should be captured within common databases and harnessed for use within higher level planning processes.

Table 5.4: Flood incident planning and management – MDSF2 and (possibly) bespoke tools within NFFS – *continued*

Supporting tools
The two distinct aspects of flood incident management, the pre-event planning and the during event management require two distinct tools: ***Pre-event (MDSF2)*** – The general-purpose tool being developed to support strategic planning would enable the effectiveness and efficiency of any given detection, forecasting, warning and response system to be explored in the planning phase. As noted above, MDSF2 will be capable of including external models and hence can be constructed at any level of detail with any level of physical representation. MDSF2 could therefore enable specific flood pathways of flood waters to be identified, temporary barriers tested and evacuation routes explored. To do so, however, the basic science of flood event management would need to be improved. ***During event (bespoke real-time support)*** – although it is outside the scope of this report to consider real-time tools, if such a tool were to be developed it would need to operate within the NFFS and provide real-time forecasts of flood risk and marshal real-time observations on flooding. ***Note:*** The above tools only consider the provision of information regarding the likely flood risks. Flood event management is as much about communication between the emergency forces as it is about understanding the probability and consequences that might occur. Additional tools to support better communication flow during events need to be considered alongside the RASP-based tools. This more comprehensive view of the decision support requirements is currently being scoped in detail through Risk Assessment for Flood Incident Management – SC050028.
How will the model be used?
MDSF2 – To be used either within the Environment Agency or by its consultants. **Bespoke real-time support** – If developed, such a tool is likely to be constructed with the goal of being available for use directly by Environment Agency Flood Incident Management staff via NFFS.
Supporting analysis method
MDSF2– As discussed earlier with enhanced capabilities regarding evacuation modelling, human behaviour to warning etc. **Bespoke real-time support** – Given that the river, coastal and pluvial loading conditions are directly forecast, the risk-based analysis could be relatively simple. This would enable the higher level RASP methods to be deployed, with appropriately improved flood spreading and overtopping models embedded within the tool.
Resolution of analysis
Spatial* –** Unrestricted in terms of the resolution of the floodplain and by minimum asset length in terms of the defences. ***Temporal – It is likely that a snapshot view will be inappropriate and time-stepping through a storm event will be required.
In what areas would users like to see improvements?
The main focus of interest of flood event management users is in the pathways (defences, flood water routes) and receptor areas (flooded areas and the socio-economic and environmental consequences). For this reason the key areas for improvement for these users will include the performance of permanent, temporary and demountable defences and flood spreading simulation (including the velocities and depths of flooding) as well as the options for evacuation and/or the purposeful diversion of the flood flow away from vulnerable areas.

6 Further recommendation for development of RASP tools

This chapter sets out some recommendations to consolidate the use of the existing RASP tools, as well as identifying some more fundamental improvements. This will provide the next generation of risk-based methods and support the delivery of the ambitious goals set out in Making Space for Water. As illustrated, the relationship between new methods and improved understanding of flooding systems and/or application to FRM practice is a subtle and intimate one. New methods can open up entirely new ways of thinking about the challenges that flood risk management confronts us with. Setting the development of such methods on the right track is therefore of the utmost importance. Without it, the aspirations in Making Space for Water will lack a sound technical basis.

The suggested evolutionary and more fundamental changes to RASP methods are discussed below under the following headings:

- Sources
- Pathways
- Receptors
- Generic system analysis frameworks
- Development of decision-specific tools
- Generic guidance
- Development of the support IT systems and software tools.

To provide some guidance on the relative priority, each development proposal is marked with a priority score. For those proposals with a high priority score an indicative cost and rank is also given. The categories for the priority score and indicative cost are as follows:

Priority score

- High priority (which are in turn ranked from 1 to 10)
- Moderate priority
- Low priority

Indicative cost

- Low (<£50,000)
- Moderate (£50,000–100,000)
- High (>£100,000)

6.1 Improvements related to sources of flooding

Overview

Two requirements are likely to form major components of any future improvements in our understanding of 'sources' of flood risk:

- An increasing need to manage all sources of flooding in an integrated manner. This will include our ability to understand the joint occurrence of different sources, responding to different physical processes and on various timescales.

- An increasing desire to move away from 'snapshot' analysis and management to a more continuous analysis. To do this the future sequencing of storm events will need to be addressed, and the statistical description of storms will need to include spatial and temporal aspects.

Research to address these longer-term issues is discussed below, together with activities aimed at improving our ability to assess flood risk in the shorter term.

Evolutionary improvements

Subject title	***Extremes analysis***		
Description	Refine data preparation, analysis and interpretation of extremes with a view to more reliable and consistent flood risk estimation. This will include approaches to routinely and explicitly expressing both statistical model and statistical inference uncertainties within these estimates in a standard way.		
Linkages	Floodsite – Task 2 Extreme analysis		
Priority	High	*Rank*	***2***
Indicative cost	Low		

Subject title	***Temporal sequencing of joint loading conditions***		
Description	To introduce temporal sequencing into joint probability long-term simulation of extreme water levels and wave conditions without detriment to the joint distribution or marginal extremes. This will require the behaviour of dynamic systems to be explored – such as morphological change and deterioration. It will also be a pre-requisite to the planning of more adaptive management actions.		
Linkages	Floodsite – Task 2 Extreme Analysis FRMRC – Infrastructure theme – Work Package 4.4		
Priority	High	*Rank*	***3***
Indicative cost	Moderate		

Change projects

Subject title	***Stochastic rainfall generation***		
Description	Integrated management will increasingly be characterised by management of the 'whole system'. This implies moving away from considering the 'source' terms simply as loading events on defences (as in NaFRA for example) but allowing rainfall to drive potential fluvial and pluvial flooding. Once achieved this will provide the basic source inputs to a more holistic view of the flooding system in keeping with the aims of Making Space for Water.		
Linkages	dti-funded SAM project – System Analysis and Management of Urban Flood Risks – led by HR Wallingford NERC FREE Programme – FRACAS Project led by the Centre for Ecology and Hydrology (CEH) EARWIG (tool for continuous simulation) developed by Newcastle University FD2105 – continuous simulation of rainfall		
Priority	Moderate in the short term (to become increasingly important as the underpinning research in SAM and FRACAS matures)	*Rank*	**-**
Indicative cost	High (to produce operational tools)		

Subject title	***Physically based run-off generation***		
Description	To utilise rainfall boundary conditions within a boarder systems analysis, new physically based run-off generation methods will be required to translate the rainfall to river and overland flow (and hence water level). Once developed, physically based run-off models will enable the effectiveness of land-use management and interventions, that seek to modify the run-off behaviour, to be explored alongside more traditional solutions to flood risk management.		
Linkages	dti SAM and NERC FREE FRACAS both have some effort devoted to improving knowledge		
Priority	High	*Rank*	**1**
Indicative cost	High		

6.2 Improvements related to pathways

Overview

The future research and development on 'pathways' can be characterised under three headings:

- **Systems analysis** – Several aspects of the 'pathway' remain to be characterised before a comprehensive system-based analysis can be routinely deployed.
- **Reliability –** Significant advances have been made in recent years through projects such as the 'Performance and Reliability of Defences' to utilise our understanding of failure modes within the analysis of asset reliability. An opportunity now exists to significantly enhance the take-up and use of reliability based models within the industry.
- **Condition characterisation/inspection** – New methods for assessing condition of assets have started to emerge over recent years and continue to develop. The relationship between the condition inspection and reliability will continue to be an important one to ensure the maximum value from each is achieved.

The areas of research outlined within this section focus on the 'systems analysis' and 'reliability modelling' aspects and should be considered alongside the programme for the Sustainable Asset Management (SAM) Theme.

Evolutionary recommendations

Subject title	***Creation of a composite national DEM***		
Description	Increasingly DEM data is available from multiple sources (NextMAP, LiDAR, in situ survey etc). The integration of different data sources and access to a national (variable resolution) DEM will be an important feature of the RASP tools. Once available this will have benefit from national policy tools to the most detailed applications. Research is required to develop this process.		
Linkages	At the time of writing it is unclear if this has already been completed via the OS Profile+ product Environment Agency Science & Technology team		
Priority	High	*Rank*	***6***
Indicative cost	High (if required)		

Subject title	***Breach growth***
Description	Assumptions on breach size are fundamental in the assessment of flood risk. Future estimates of flood risk, where climate change and deterioration of the assets are considered, are particularly sensitive to assumptions of breach growth (as shown for example within the RASP modelling undertaken as part of the TE 2100 project). Over the past five years a number of advances have been made regarding our ability to model breach growth. However, our understanding remains limited to specific situations and embedded within complex models such as HR Breach. A hierarchy of breach models from simple governing rules (as used in NaFRA) to more complex models will need to be developed and benchmarked.

	Once developed, the new methods can readily be absorbed by the RASP family of tools.		
Linkages	Defra/Environment Agency programme (e.g. embankments research) and the EC (e.g. IMPACT, Flood*site* and Hydrolab projects) as well as research funded through FRMRC (Work Package 4.1).		
Priority	High	*Rank*	***2***
Indicative cost	Moderate		

Subject title	***Characterising asset blockage within a system analysis***		
Description	Blockage of culverts or bridges is often an important issue when considering flood risk. Blockage is usually caused by floating debris from natural and/or anthropogenic sources, which collects on the piers, abutments and at the soffits of bridges and culverts. The probability of blockage and the percentage of flow area blocked are difficult to estimate and research into the subject is severely hampered by the difficulty of obtaining useful data. The probability of a particular structure blocking and the extent of blockage (which are key questions for new structure design) is a subtly different issue to the additional flooding risk blockage may present along a whole watercourse. This project would focus on the development of methods to enable blockage to be incorporated into the flood risk assessment. Once developed, the new methods can readily be absorbed by the RASP family of tools.		
Linkages	NaFRA – under discussion for NaFRA 2007 development, MDSF2 – variation to consider point assets		
Priority	High (provides an opportunity for a measured step forwards)	*Rank*	***5***
Indicative cost	Low		

Subject title	**Characterisation of drainage infrastructure within a system analysis**		
Description	Making Space for Water calls for a more integrated approach to the assessment and management of flood risk. A prerequisite to such an analysis will be to develop new approaches to characterising the performance and failure of drainage infrastructure. This will enable urban drainage and above-ground infrastructure to be considered within the context of a common analysis framework.		
Linkages	FRMRC Work Package 4.4 and RPA 6 dti SAM (note dti SAM does not include any significant activities on asset reliability but is developing methods of incorporating above and below ground infrastructure into a RASP analysis framework)		
Priority	High	*Rank*	***4***
Indicative cost	High		

Change projects

Subject title	***Broad-scale reliability-based assessment of natural systems***		
Description	Extending the reliability analysis to incorporate the variability of the natural components within a given system remains a significant and important challenge. Proper characterisation of beach performance, including the influence of beach control structures, remains a significant challenge. In particular, the behaviour of beach systems exhibits important temporal and spatial dependencies – both in an alongshore sense and in a vertical sense (due to variations in the underlying deposits). Research challenges exist in terms of predicting long-term shoreline evolution and local short-term fluctuations in beach levels, and the incorporation of these changes into the assessment of defence performance (either in terms of flood or erosion risk). Channel morphology can also affect system flood risk and fluvial and tidal morphology should also be considered here.		
Linkages	These issues are, in part, being tackled under both the PAMS and RACE projects. However, at present both projects make a number of significant simplifications regarding the interactions (temporally and spatially) between defence lengths. These shortcomings will need to be addressed to support more strategic long-term planning of coastal management as well as the optimisation of beach management actions for example.		
Priority	Moderate	*Rank*	***7***
Indicative cost	High		

Subject title	***Characterisation of the performance of point assets (barriers, gates and pumps etc) within a RASP-based system analysis***		
Description	In the recent past a number of projects have reviewed the performance of barriers, gates and pumps. To date, however, it has not been possible to provide a unified and accepted method of representing the performance of such assets in a meaningful way and incorporating this representation within the system-based risk analysis. Recent advances through projects such as the Thames Barrier and Associates Gates undertaken by Atkins for the Agency and the TE 2100 project have provided workable solutions to some of these issues but now need extending and formalising into industry guidance. Once developed, the new methods can readily be absorbed by the RASP family of tools.		
Linkages	MDSF2 – Recent discussions between the PAMS and MDSF2 teams have highlighted the need to include point assets within the systems analysis. It is likely that a sub-set of point assets will be considered in the development of MDSF2; however, this is likely to require extension to enable a full description of point assets. Failure on Demand – led by RMC Flood Event Management Scoping Study – led by HR Wallingford TE 2100 – IA system model (HR Wallingford) and TBAG (Atkins)		
Priority	High	*Rank*	***3***
Indicative cost	High		

Subject title	***Statistical representations of asset deterioration***		
Description	An improved understanding of how different materials deteriorate with time or under load is starting to emerge and is likely to be subject to significant research within the SAM Theme and elsewhere. The use of this information within a time-dependent system analysis will be a significant challenge over the coming years. This will involve developing new ways of characterising the improved understanding of deterioration processes using statistical methods that capture the significant uncertainties and can be linked to both 'snapshot'-based risk analysis and continuous simulation risk models. Inclusion of the deterioration processes within the risk analysis frameworks in a structured and more automated way than is currently possible will be a vital precursor to robust whole-life costing and optimisation of interventions strategies. The challenge involved in making significant headway here should not be underestimated and reflects the limited available data on which to base our understanding. Note: This project relies on a combined approach between MAR and SAM themes.		
Linkages	SAM Theme TE 2100 sponsored PhD (HR Wallingford/Newcastle University) NADNAC and TE 2100 provide insights into simplified snapshot methods		
Priority	High	*Rank*	***8***
Indicative cost	High		

Subject title	***Surface flood spreading (Inundation modelling) – development and benchmarking***
Description	Over the next few years two types of model are likely to be used: simplified models for use within a broad-scale modelling approach and highly detailed models to refine broad-scale estimates in important areas. Both require research, including: ***Rapid spreading techniques*** – To satisfy the need of risk-based tools to include multiple realisations of inundation there is a need for an accurate yet rapid (in terms of run-time) inundation model. Once the availability of a reliable national DEM becomes a reality, the inclusion of a rapid flood spreading model will significantly improve the reliability of RASP modelling. Once developed, this could be utilised in all of the RASP tools and, where required, more detailed models could be used to refine the results for a limited (priority) set of scenarios. ***Non-linear shallow water model*** – the use of non-linear shallow water models for routine study is on the verge of becoming a reality. Models recently developed by HR Wallingford and at several universities provide a firm foundation for developing suitable tools. It is unlikely to be appropriate for the MAR Theme to fund significant developments in this area, but the industry would benefit significantly from detailed benchmarking and demonstration of the capability offered by these new generation models over and above more routine two-dimensional models.

	Benchmarking of spreading models – Through the FRMRC and Flood*site* projects a number of models are being compared in a scientifically rigorous manner. A measured step forward would be to formalise these tests into a standard set of model tests and benchmarking procedures.		
Linkages	RFSM (initial development of a rapid flood spreading model has been undertaken by HR Wallingford within Floodsite and tested within the TE2100 Project). The RSFM model provides a useful starting point and is likely to be embedded within MDSF2. However, future developments are required before this can be considered a robust model for inclusion within other RASP-based tools such as NaFRA and PAMS. Floodsite and FRMRC benchmarking activities 2D model benchmarking study (ongoing)		
Priority	High	*Rank*	***1***
Indicative cost	Low/moderate		

Subject title	***Defence reliability analysis tool (RELIABLE)***		
Description	As the industry becomes increasingly familiar with risk-based planning it will be appropriate to move towards a reliability based design (where engineering solutions are optimised against risk-based safety standards). This will allow increased efficiency in design. To achieve this in practice there is now a need to develop a specific design aid that enacts best practice design guidance and failure modes within a reliability framework. This would enable the design and assessment processes to be more closely aligned. It would also facilitate the rapid uptake of the new understanding on failure into the design process.		
Linkages	SAM Theme Floodsite Task 7 FRMRC Work Package 4.4		
Priority	Moderate	*Rank*	**-**
Indicative cost	Moderate/high		

6.3 Improvements related to receptors

Overview

The future research and development on 'receptors' will need to consider a wider range of receptors and broaden the issues considered to include social and environmental as well as economic aspects. There will also be a need to explore how the resilience of particular system components can be increased to better withstand the impacts of flooding events.

<table>
<tr><td>Subject title</td><td colspan="3">Improved and wider assessment of consequences</td></tr>
<tr><td>Description</td><td colspan="3">To support Making Space for Water an increasingly wide range of receptors will need to be considered within the risk assessment. To enable their inclusion within a structured risk assessment the description of the impact must relate, in a quantified manner, the potential harm to a physical characteristic of the flood event (e.g. depth, duration, velocity, pathogenic load). Some of these relationships are already well established, whereas others will demand significant research before they can be used within a quantified risk analysis.

• Property risk – Significant deficiencies within the NPD2 have been highlighted through projects such as NaFRA. NPD2 provides a vital dataset that underpins much of the risk-based analysis. Considerable effort will be required to improve this dataset – including the improved and more intelligent use of multiple data sources from the Ordnance Survey, the Valuation Office and the Environment Agency itself.
• People risk – Further research is required here to extend the flood risk to social impacts, for use with the RASP-based tools. In particular the methods developed will need to enable the number of people at risk of death or serious injury to be estimated and to identify the locations of vulnerable people within flood risk areas. The methods will need to be capable of differentiating the impacts of flooding on different groups of people, especially the vulnerable.
• Environmental consequences – To understand the impacts of flooding on different natural environments is also important. To support a more integrated and balanced approach to flood risk management, however, quantified methods will be required. This will need consideration of a wide range of receptors, such as flora, fauna, habitats, wetlands etc. It may also need to consider some environmental processes as receptors on which flood risk can have positive or negative impacts.
• Communications and transport infrastructure including telecommunications etc.

To be effective it will be important that the characterisation of this broad range of impacts is provided within a common framework that can be used within a system model.</td></tr>
<tr><td>Linkages</td><td colspan="3">Many projects will have a bearing here, including:
Floodsite – Task 9
NaFRA
FRMRC – RPA 7</td></tr>
<tr><td>Priority</td><td>High</td><td>Rank</td><td>1</td></tr>
<tr><td>Indicative cost</td><td colspan="3">High</td></tr>
</table>

Subject title	***Building in resilience (non-structural responses)***		
Description	Increasingly a focus will be placed on managing and reducing the consequences of flooding. As highlighted through the Foresight project, improving the inherent resilience of potential receptors can be an efficient and effective risk management tool. Further effort will need to be devoted to understanding how resilience can be improved through different measures and instruments and how the potential improvement can be reflected within the risk assessment methods (e.g. through the modification of existing depth-damage curves).		
Linkages	*CRUE*[4] *– non-structural measures* *TE 2100 – non-structural methods* *Foresight* *Resilient of buildings – dti/CIRIA* *Floodsite*		
Priority	Low (depending on the scope of CRUE)	*Rank*	**-**
Indicative cost	-		

[4] The CRUE network has been set up to consolidate existing European flood research programmes, promote best practice and identify gaps and opportunities for collaboration on future programme content related to, for example, severe river and coastal flooding, flood risk management and mitigation and climate change.

6.4 Generic system analysis frameworks

The original RASP development was focused on methods to estimate the flood risk associated with systems of defences at a given instance in time. Two fundamental extensions are now necessary:

- *To deal with flooding systems as being dynamic over a wide range of timescales*. The treatment of long-term change, and associated uncertainties, is fundamental to strategic planning, as Foresight has illustrated. It is particularly important on the coast, where adaptation to long-term morphological change is one of the most pressing challenges. Flood risk management is a process of intervening in dynamical systems and hence the FRM tools must reflect this dynamic behaviour. Work Package 4.4 of FRMRC has already started developing time-dependent analysis frameworks, but significant future work will be required before practical and robust methods can be established.

- *To deal with flooding systems from a more holistic point – extending the significant advances made through RASP to include system behaviour beyond the performance of defences.* For example, the fluvial flooding system starts with rainfall (and the climate changes that may modify rainfall) and includes processes of run-off, subsurface storage and groundwater flows. To provide effective support to Making Space for Water, this broader view of the flooding system will need to be embraced.

Evolutionary improvements

Subject title	***Risk attribution – further development***		
Description	Methods to enable the risk contribution of particular actions to be uniquely stated need to be developed to support both funding and intervention decisions. The practicality and utility of this has been demonstrated in terms of attributing risk to 'whole assets' but further research is required to enable risk attribution in increasingly complex situations. For instance, the use of uncertainty methods would enable the contribution of individual components of an asset and the data uncertainties to be associated with a 'risk attribution'. This could then be used to guide funding decisions.		
Linkages	Floodsite and TE 2100 – variance-based sensitivity analysis methods are being trialled to attribute risk to all components of the source, pathway and receptor system – i.e. what contribution has the uncertainty on the water level to the estimate of risk? FRMRC Work Package 4.5 (Infrastructure)		
Priority	High	*Rank*	**2**
Indicative cost	Moderate		

Change projects

Subject title	***Flooding from all sources***		
Description	Achieving integrated flood risk management involves the management of all flood sources (e.g. fluvial, coastal, groundwater and pluvial influences) and responses. However, integration of flooding from sewers, groundwater and pluvial floods in flood system models potentially leads to an escalation of complexity and a multitude of models operating at a range of different scales (temporal and spatial). A conceptual framework is required to enable model-based analysis of coupled systems to happen in practice. This should lead to a programme to develop methodologies and test these in case studies. A detailed scoping of the possible approaches to the inclusion of a wider range of sources within a coherent risk framework would provide a useful guide to more detailed research. This project will build on the dti SAM project and associated SAM Theme funding to demonstrate and refine the emerging methods within the context of the MSfW pilots.		
Linkages	*dti SAM and supporting Environment Agency funding*		
Priority	*High*	*Rank*	***3***
Indicative cost	*Moderate*		

Subject title	***Use of continuous simulation data in risk analysis***		
Description	An understanding of whole-life performance underpins successful sustainable management. This includes knowledge of future risks taking account of various time-dependent processes – including demographic change and climate change as well as asset deterioration. In recent years new methods have been developed to generate synthetic time series of loads such as river flows or tide levels. These time series methods are attractive in the context of systems reliability analysis because they enable time-dependent interactions to be represented. For example: • climatic and isostatic changes • deterioration • ground settlement • development in flood risk areas • socio-economic changes. However, because flood defence system failure is often associated with extreme events, it is necessary to simulate very long time series in order to include a representative sample of extreme events. Further research is required to develop efficient sampling/analysis methods so that the benefits of continuous simulation data can be realised in practical computer run-times.		
Linkages	FRACAS (NERC)		
Priority	High	*Rank*	***1***
Indicative cost	High		

6.5 Development of decision-specific tools

Overview

To develop a series of tools required to support the range of flood management decisions in a consistent and hierarchical fashion will require a concerted effort or R&D and strong business collaboration. The development of the existing tools and possible future tools are discussed below.

Evolutionary improvements

Subject title	***National policy planning (NaFRA)***		
Description	A number of methodological advances over the coming two to three years will be required. The most significant of these relate to the inclusion of an improved flood spreading methodology. The details of the proposed improvements are currently being developed by the NaFRA team in consultation with the MAR Theme champion but could include: • the rapid flood spreading methods; • allowing partial dependencies in loading; • a wider range of risk metrics; • improved what-if scenario testing capability to support policy appraisal and the assessment of climate and social change. These advances will go hand-in-hand with improvement of the support data and will provide a stable basis for long-term monitoring of year-on-year changes in risk. The NaFRA models can also be used to explore the nature of the national exposure to risk, including: • What is the spatial coherence of risk (i.e. what might be expected in a widespread event)? • What is the national exposure to risk at different return periods (in addition to simple expected annual damages (EAD) aggregation)? Notes: • A more detailed development proposal is under preparation at the time of writing. • Further improvements with the source, pathway and receptor understanding discussed in previous chapters will of course need to be played through into PAMS.		
Linkages	NaFRA delivery projects		
Priority	High	*Rank*	***1***
Indicative cost	Low/high (reflecting the degree of sharing of development costs with the NaFRA operational projects)		

Subject title	***Strategic planning (MDSF2)***		
Description	An ongoing project within the MAR Theme is currently defining the development of the so-called MDSF2 tool. In the first instance this will include the extension of MDSF1 to incorporate the existing RASP functionality. Future versions of MDSF will be needed to develop a more holistic strategic planning tool capable of supporting Making Space for Water. This latter goal will be a significant challenge. Note: Further improvements with the source, pathway and receptor understanding and associated software modules discussed in previous chapters will of course need to be played through into MDSF2.		
Linkages	MDSF2 – Discussions during the detailed specification stage together with the PAMS team has highlighted the need to extend the RASP framework to include point assets. At the time of writing, it is unclear whether this will be taken forward within MDSF2		
Priority	No action at present	*Rank*	**-**
Indicative cost	Already committed		

Subject title	***Asset management planning (PAMS)***		
Description	An ongoing project within the SAM Theme is developing the PAMS toolset. Note: Further improvements with the source, pathway and receptor understanding and associated software modules discussed in previous chapters will of course need to be played through into PAMS.		
Linkages			
Priority	No action required at present	*Rank*	**-**
Indicative cost	-		

Change projects

Subject title	***Flood incident management planning tools***
Description	Increasingly flood incident management is likely to play an important role as part of an integrated approach to flood risk management. For the Flood Incident Management (FIM) Theme, a new generation of RASP-based tools would offer significant support to flood incident planners and place flood incident management on a common basis alongside other business planning activities. The two elements of flood incident management (real-time and pre-planning) will both require support, including: ***Planning tools*** – The information to support flood event management planning is similar to other decisions – however, the emphasis is more directly related to people risks and the range of interventions is primarily associated with modifications to forecasting, warning and evacuation procedures (although in some situations more active management of the sources and pathways of flooding – for example through the use of 'fuse plugs' and preferential flood routes, deployment of temporary/demountable defences, rapid breach repair etc) may also be a significant component. The existing RASP methods can be used to support many of these choices directly but will need to be modified to

	reflect the specific needs of the flood incident management community, in a similar way to the development of PAMS and the MDSF2. For example, such a tool would support the spatial definition of Flood Warning Flood Risk Areas (FWFRAs). ***Real-time support tools*** – Decision-specific tools are also needed to provide real-time guidance to support probabilistic 'flood' forecasting; moving away from '*source*' forecasting (e.g. water level/wave conditions) to '*risk*' forecasting as recommended in the recent Coastal Flood Forecasting Project. As outlined in the Coastal Flood Forecasting Best Practice Guide completed 2005, the present forecast systems generally provide predictions for the source variables. It is envisaged that forecasts would have a greater value if they predicted flood extent. This is a constrained problem where the spatial distributions of probability, depth, velocity and defence contributions are conditional upon a forecast load term. In order to be able to run this type of simulation in real-time, it is likely that a spectrum of cases would need to be run in advance and the results intelligently interpolated to provide predictions. If this can be achieved, this could make a significant contribution to flood event management.		
Linkages	Coastal Flood Forecasting (FIM Theme) Floodsite – Tasks 17 and 19 MAR Scoping – Reliability of flood event management		
Priority	High	*Rank*	***2***
Indicative cost	High		

Subject title	**Development Control and Regulation**		
Description	While the NAFRA model will remain useful for exploring national and regional development plans, at the level of the individual application or even the Local Development Framework, a more detailed model will be appropriate. The MDSF2 and PAMS models may well assist here, and for this reason it is suggested that this study take place after completion of Phase 2 of the development of the PAMS and MDSF2 models in order that the best of these developments can be adopted and/or adapted into any bespoke model for regulation.		
Linkages	Risk assessment for new development		
Priority	High	*Rank*	***3***
Indicative cost	Moderate		

6.6 Generic guidance

Overview

As with the introduction of any new methodology, there is a need for good guidance and the presentation of a range of applications that demonstrate the value and robustness of the approach. In many cases this will include the need to set out how to interpret outputs in the context of the evidence they provide to the decision-making process.

Subject title	**Validation and calibration of probabilistic models**		
Description	The move towards a risk-based analysis framework presents decision-makers with a new challenge in terms of calibrating and validating results. A significant deficiency at present is an inability to provide a detailed 'report' on the uncertainties and reliability of the results based on ground-truthing of the outputs and how users should do this ground-truthing for themselves. To improve buy-in and demonstrate creditability, the issue of validating probabilistic and uncertain outputs will need to be addressed. The development of validation procedures will be an important issue for all tools supported by RASP methods. A key aspect will be to explore and demonstrate the reliability of the approach and to establish the key drivers of uncertainty through sensitivity testing and comparison with more detailed models/real-life observation.		
Linkages	NaFRA – Ground-truthing report TE 2100 – uncertainty analysis (ongoing) RASP sensitivity analysis report FRMRC RPA9 – Risk and Uncertainty		
Priority	High	*Rank*	***1***
Indicative cost	Moderate		

Subject title	***Robustness analysis***		
Description	Increasingly policy choices will rely on our perceived 'robustness' of the options chosen. In the face of significant climate, demographic and budgetary uncertainties structured robustness analysis methods will be required to aid in the decision process. For example, within the Foresight flooding project simple 'coupled' climate and socio-economic storylines were developed. Within the context of catchment or shoreline management planning a broader set of storylines must be developed and analysed. Robustness analysis could provide an opportunity to explore the future possibilities in a more complete and efficient way. Initial developments are under way within Flood*site* but these will need to be further developed before suitable for inclusion into MDSF and NaFRA tools.		
Linkages	Floodsite – Task 14/18 Long-term planning (HR Wallingford) CRANIUM project on risk, uncertainty and decision analysis for infrastructure systems (Newcastle University)		
Priority	High	*Rank*	***2***
Indicative cost	*Moderate*		

Subject title	***Communication of methods and tools***		
Description	The communication of uncertainty outputs remains a particular issue. Simple presentation methods and the development of typical 'uncertainty' measures will help maintain a structured debate. One particular challenge will be to express spatial and temporal uncertainties easily yet completely.		
Linkages	FRMRC RPAs 7 and 9 are doing joint work in this area Tyndall Centre work on flood and erosion risk communication		
Priority	High	*Rank*	***3***
Indicative cost	Low		

Subject title	**Demonstrate the hierarchy in action through exemplar pilots**		
Description	The lack of a clear understanding of how the RASP methods will work in practice remains a barrier to broader acceptance. Experience has shown that using pilot studies provides an excellent vehicle to ensure the research is practical and robust and is also useful in promoting take-up. A number of pilot sites could be identified where the process of planning is demonstrated from policy to action, including all activities (policy appraisal, strategy planning and delivery planning) and applying the various models. This could then be used to demonstrate 'best practice' examples and provide a mosaic of outputs to highlight how the different techniques fit together (e.g. techniques from NaFRA, MSDF2 and PAMS and how the data will come together over the next 5–10 years).		
Linkages	-		
Priority	High	*Rank*	***4***
Indicative cost	Moderate (if linked to ongoing operational activities)		

Subject title	***Multi-criteria methods***		
Description	RASP methods will need to respond to the needs of decision-makers in the area of project appraisal. The PAG guidance is due to be revised and new guidance may place more emphasis on multi-criteria methods. This could include, for example, assessing social, economic and environmental outcomes within some sort of scoring and weighting framework. This may include risk (e.g. what are the likelihoods of particular outcomes?) As policy and guidance is introduced, RASP methods will need to develop so that appropriate and relevant outputs are provided.		
Linkages	MCA Scoping Studies – RPA Task 9 – Floodsite		
Priority	Moderate (linked to the Policy theme)	*Rank*	**-**
Indicative cost	Low (to develop the framework – the investment to develop the supporting methods to quantify the different criteria could be significant)		

6.7 Development of the support IT systems and software tools

Two issues will need to be addressed in parallel with RASP development projects, to ensure the RASP family of tools are implemented effectively and efficiently:

Reuse of common software modules where appropriate – A parallel project, FD2121, is currently exploring these issues and should be read in conjunction with this report.

Use and reuse of data – At present the information to support the RASP methods and the value-added data generated through the RASP analysis is difficult to obtain and store. National databases such as NFCDD will need to be extended to enable the exchange and reuse of data through the hierarchy of planning activities and associated tools. For example, the fragility information gathered/developed within PAMS should be made available to strategy planning and policy planning activities. Such a link is currently difficult to make. Advances in the area of data for all FRM purposes will be fundamental to progress in risk-based methods.

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Surendran 2006. Personnel communication

List of abbreviations

AES	afflux estimation system
CES	conveyance estimation system
CFMP	Catchment Flood Management Plan
DEM	digital elevation model
DPSIR	Drivers-Pressures-State of system-Impacts-Response
DSS	decision support system
dti	Department of Trade & Industry
DTM	digital terrain model
EAD	expected annual damages
FCERM	Flood and Coastal Erosion Risk Management
FIM	Flood Incident Management (Theme Advisory Group)
FRA	Flood Risk Assessment
FRACAS	Flood Risk Assessment under climate ChAnge Scenarios
FREE	Flood Risk from Extreme Events
FRM	flood risk management
FRMRC	Flood Risk Management Research Consortium
FWFRA	Flood Warning Flood Risk Areas
GUI	graphical user interface
IA	Intervention of Assets
ICM	Integrated Catchment Management
LiDAR	Light Detection And Ranging
MAR	Modelling and Risk (Theme Advisory Group)
MCA	Multi-Criteria Analysis
MDSF2	Modelling and Decision Support Framework (phase 2)
MSfW	Making Space for Water
NADNAC	National Assessment of Defence Needs and Costs
NaFRA	National Flood Risk Assessment
NCPMS	National Capital Programme Management Services
NERC	Natural Environment Research Council
NFCDD	National Flood and Coastal Defence Database
NFFS	National Flood Forecasting System
NPD	National Property Dataset
PAG	Project Appraisal Guidance
PAMS	Performance-based Asset Management System
PPS25	Planning Policy Statement 25
RACE	Risk Assessment of Coastal Erosion (Project FD2324)
RASP	Risk Assessment for System Planning
RMC	Resources in Measurement and Control
RPA	Research Priority Area
SAM	Sustainable Asset Management (Theme Advisory Group)
SFRA	Strategic Flood Risk Assessment
SFRM	Strategic Flood Risk Management
SMP	Shoreline Management Plan
SPD	Strategy and Policy Development (Theme Advisory Group)
S-P-R	source-pathway-receptor
TAN 15	Technical Advice Note 15
TE 2100	Thames Estuary 2100

Appendix 1: Background to MAR theme and related R&D projects

The overall objectives of the Modelling and Risk (MAR) theme are:

(i) to develop and deliver better risk assessment and management, as needed by the FCERM business and science, directly aimed at improving decision-making; and
(ii) delivery to reduce flood and coastal erosion risk, and taking into account future uncertainties.

The specific objectives are to:
- improve knowledge and process understanding;
- develop methods, models and assessment tools;
- integrate assessment and appraisal methods, system models and applications.

A previous Defra/Environment Agency R&D Technical Report FD2302/TR (*Risk, Performance and Uncertainty in Flood and Coastal Defence – A Review*, 2002) has set out a vision for the development of coherent, user-focused, system-based, risk assessment and decision support tools for Flood and Coastal Risk Management. The initial hierarchical method to flood risk assessment for system planning was developed and published in the Defra/Environment Agency R&D Technical Report W5B-030/TR (*Risk Assessment of Flood and Coastal Defence for Strategic Planning* – RASP, 2004).

The development of the first generation of Risk Assessment for System Planning (RASP) methods commenced in 2001 and has continued to evolve since 2004. Throughout the joint Environment Agency/Defra R&D programme and other partnership projects (e.g. FRMRC, Flood*site*, TE 2100) tools have been developed for risk assessment to meet specific needs. Modules required for risk assessment in structural (Performance based asset management – SC040018) and non-structural measures (Risk assessment flood event management – SC050028, Risk assessment new property development – FD2320) including coastal erosion (Risk assessment for coastal erosion – FD2324), have been developed or are under development. They include assessments of the source (e.g. climate change, joint probability), pathways (e.g. defence performance, flood inundation) and receptors (e.g. risks to people).

These projects helped the Office of Science and Technology's Flood Foresight projects, the Environment Agency and Defra to assess national flood risk in order to prioritise investment in flood risk management, flood risk mapping and planning at a range of scales. For example, RASP is helping NaFRA, MDSF is helping CFMP and some of these tools have been successfully used in TE 2100.

These studies have provided encouraging results and it is now accepted that the approach is beginning to mature. In order for the tools to be more widely used there is now a need for the tools to be integrated into a holistic systems framework to support all FRM activities. The studies also identified some of the barriers/limitation for the risk model development and usage and highlight the need to:
- involve the proposed users during the development of models;
- improve the users knowledge and understanding of the models;
- ensure that the processes within the models are open, transparent, flexible and sufficiently rigorous for the decisions they support;

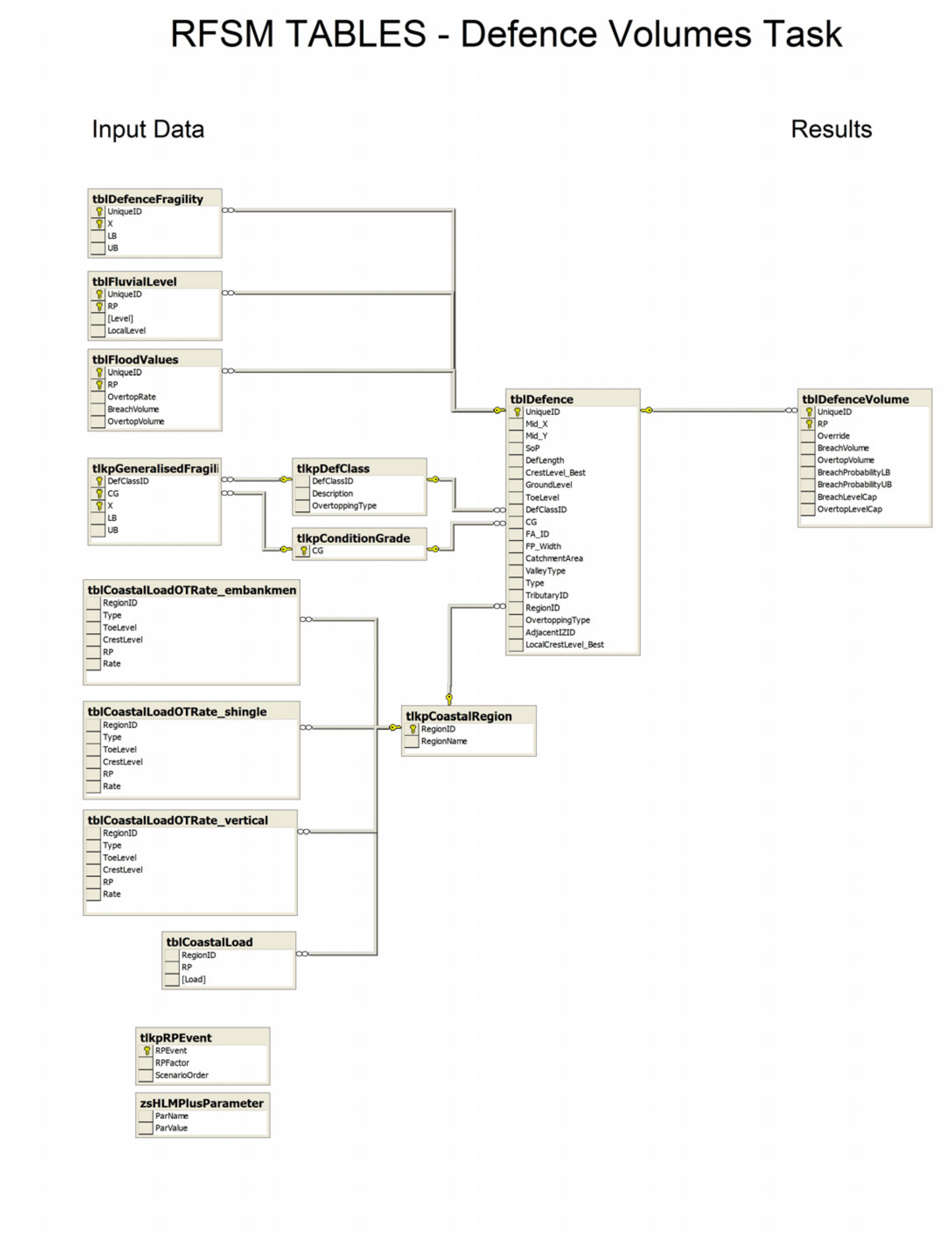
- make the tools compatible with the Environment Agency's computer systems and capacity;
- include an efficient user interface;
- provide adequate training.

To respond to the above concerns the MAR theme has initiated a number of scoping studies to improve models for risk assessment and decision-making. These models will be built within a 'systems' framework. The MAR theme has identified the need to develop these types of models on a more strategic, long-term basis. The following scoping studies have been undertaken to identify the needs and set out either guidance or a plan for future research and development.

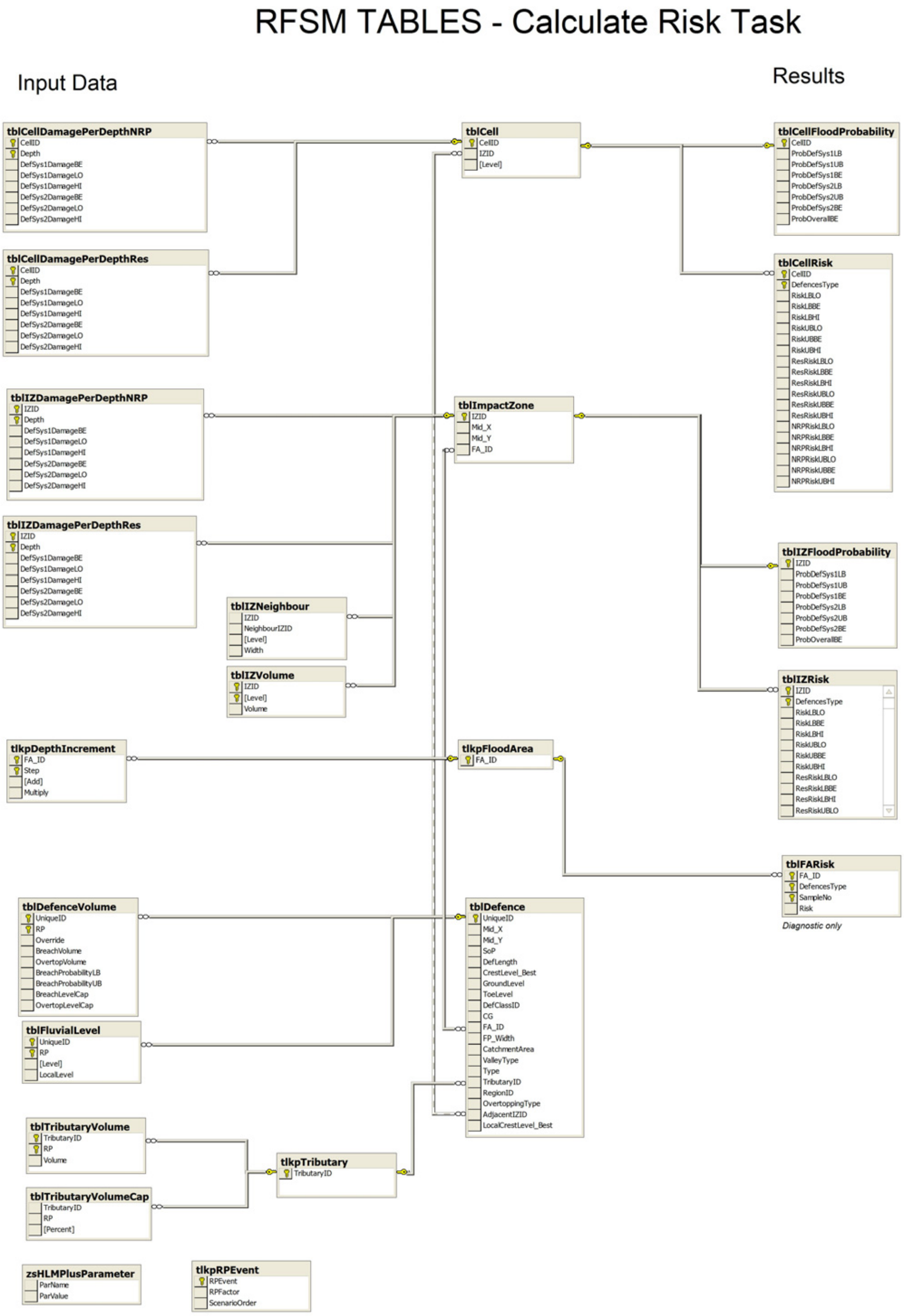
- Scoping the development and implementation of *RASP* – (Risk Assessment for System Planning) related Flood and Coastal Risk Models (SC050065).
- Software requirements for Joint FRM R&D Programme modelling outputs and architecture specification for RASP family outputs (FD2121).
- Flood Risk Management Research Consortia Risk & Uncertainty Tools and Implementation (FRMRC - RPA9).
- Broad Scale Modelling – a Scoping Study on catchment scale modelling for MAR vision (FD2118).
- Estuary Management System Scoping and Dissemination – ERP2 (FD2119).

Appendix 2: Outline data flows to be utilised in NaFRA, MDSF2 and PAMS

Calculating inflow into the floodplain



Calculating flood probability and risk



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