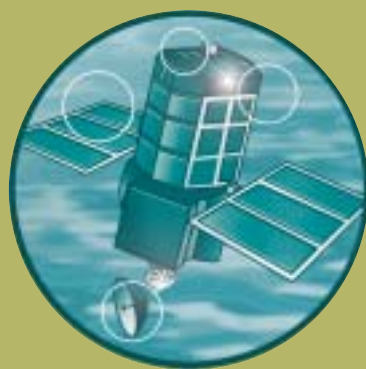


Risk assessment for flood incident management: framework & tools

R&D Technical Report SC050028/SR1

Product Code: SCHO0307BBIK-E-P



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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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Science at the Environment Agency

Science underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us and helps us to develop monitoring tools and techniques to manage our environment as efficiently and effectively as possible.

The work of the Environment Agency's Science Group is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

The science programme focuses on five main areas of activity:

- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen
Head of Science

Executive Summary

Failure to deliver effective flood incident management (FIM) can give rise to an increased risk of harm to people, as well as pose a significant risk to the Environment Agency's business and reputation. The success of the FIM process is, however, dependent on a large number of operational components that include rain and flow gauges, telemetry and communication systems, hydrological and hydraulic models, and human activity, such as data interpretation and decision making. Rather than 'failure', the concept of 'performance' of the FIM process needs to be addressed in the FIM. Ranges of performance indicators are suggested for both the process and outcomes of FIM.

There is a need for a tiered risk-assessment process similar to that employed by the Environment Agency in flood risk management. As the FIM process is a complex system, there is a need for a risk screening tool to assist flood incident managers, practitioners and planners to focus their efforts on the 'weakest links' in the process. It is proposed that a three-tier risk-assessment framework be set up to assess the FIM process. As part of this project, a number of tools were researched for use in a framework for risk assessment in FIM. The research indicates that the tools that could be useful to assess the risk in the FIM process comprise:

Tier 1	development of performance indicators and the Analytic Hierarchy Process for use as screening tools in the risk assessment process;
Tiers 2 and 3	use of Bayesian networks needs to be further investigated for various components of the FIM process.

The risk assessment framework should have the following characteristics:

- be simple to construct;
- adaptable;
- not require specialist expertise to master and communicate.

It is recommended that the tools are tested using key stakeholders and information collected during recent flood incidents.

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1. Introduction

1.1 Background to the project

Failure to deliver effective flood incident management (FIM) can give rise to an increased risk of harm to people, as well as pose a significant risk to the Environment Agency's business and reputation. The success of the FIM process is, however, dependent on a large number of components that can broadly be categorised into:

- detection;
- forecasting;
- warning;
- response.

The delivery of these processes involves a complex combination of human and technological components. Recent floods at Boscastle in 2004 and Carlisle in 2005 showed that the system can be vulnerable to 'failure' if one or more of these elements do not operate successfully. It is important that the response part of the FIM system also includes groups such as the 'blue light' responders (for example, the police) and other organisations. Also, the risk of failure that can occur in this part of the FIM process, outside the Environment Agency's direct control, needs to be examined.

There is a need to develop a risk assessment methodology or framework to assess both the FIM process in a holistic manner and its individual components. This risk assessment framework needs to be able to:

- assist us to understand the behaviour of the process;
- improve the performance of the process;
- understand where the 'weak links' in the process may be;
- understand the potential consequences of 'weak links';
- mitigate the potential consequences of 'weak links'.

The purpose of the research was to formulate a framework and outline tools that could be used to assess the probability and impacts of various modes of 'failure' in the chain of response from flood forecasting and warning to dissemination and emergency response. The framework and tools will assist the Environment Agency to evaluate the risk management measures that would improve the effectiveness and resilience of their FIM systems. They will also help to ensure consistent and efficient decision making, both strategically and operationally, and will help to reduce risks to people and property from floods.

Effective FIM depends on the operation of complex, interacting systems over a wide range of conditions. These systems have many different functions, such as forecasting, warning, emergency planning, emergency operation and the behaviour of institutions and individuals. All of these can fail to perform as intended in many different ways. Each failure has consequences that propagate to other subsystems and then to the whole system.

Several risk management approaches are in use or being developed for flood risk management in general. However, these were focussed mainly on the longer term mapping of flood probabilities (for example, risk assessment of flood and coastal defence for strategic planning (RASP)) and the planning, design and maintenance of defences (for example,

performance based asset management system for flood defences (PAMS)) rather than on the management of actual flood incidents. This project aims to plan the development of a systematic, risk-based approach to prioritisation and decision making for FIM.

1.2 Project objectives

1.2.1 Overall project objectives

When the Environment Agency formulated this research in August 2005, the plan was for a two- or three-phase project. This report details the findings of the Phase 1, the planning phase.

The main aim of the project, as a whole, is to establish risk assessment and management methodologies to:

- assess current FIM systems and procedures to identify sequences of events and failures that could threaten the accuracy, timeliness and performance of current flood forecasting and warning and reactive FIM activities;
- carry out a 'hazard analysis' to identify the probabilities and consequences of failure of the system, including component failures, operational failures and failure of the supporting infrastructure during the flood incident;
- analyse the complex FIM system, to take account of the role of the various components in the delivery of successful FIM, assess the risk and uncertainty of the current system and develop strategies to manage the risks through improved design and operation of FIM systems.

The overall objective of the project is 'to develop and disseminate an improved system-based' methodology and effective practice guide on risk assessment and management to enhance the reliability and efficiency of the Environment Agency's FIM.

1.2.2 Phase 1 project objectives

Specific Phase 1 objectives defined in a *Definition and Boundary Setting* report produced in January 2006 were to:

- define what is meant by a 'failure' of the FIM process;
- produce an outline method by which 'failure' in the existing forecasting, warning and response system can be identified and to test this in a case study;
- develop a conceptual framework to identify the risk of the operational failure of active flood-defence assets (for example, barriers and gates);
- produce a conceptual framework to analyse and assess the aggregate risk as a result of failure of the supporting infrastructure (for example, telecommunications, utilities, transport infrastructure);
- investigate and outline requirements for a complex systems model of the FIM system;
- develop a framework by which risk assessment for FIM can be achieved.

1.3 Project methodology and approach

1.3.1 Project Work Packages

A series of seven Work Packages (WPs) were developed:

WP	Title
WP0	Report to define the output, boundaries and definition of the main Work Packages
WP1	Failure, performance and response in flood incident management
WP2	Impacts of flood defence asset and operational failure
WP3	Risks and consequences of failure of reactive mitigation measures
WP4	Understanding and application of complex systems risk assessment models
WP5	Recommendations for minimising flood incident management system vulnerability
WP6	Project management

The output, boundaries and definition report produced as part of WP0 refined the outputs of WP1 to WP5 as follows:

WP1 outputs

- Define what is meant by a 'failure' of the FIM process;
- Produce an outline method by which failure points in the existing forecasting, warning and response system can be identified and to test this in a case study;
- Define the response part of the FIM process;
- Assess what does and does not provokes a response among key stakeholders other than the Environment Agency.

WP2 outputs

- Identify the risk of failure of active flood defence assets (for example, gates, demountable flood defences) as a result of operational issues (for example, access to a site, breakdown in communication);
- Develop a conceptual framework to identify the risk of the operational failure of active flood defence assets.

WP3 outputs

- Identify the interdependence between the supporting infrastructures that has an effect on FIM;
- Assess the causes and consequences of the failure of the supporting infrastructure;
- Produce a conceptual framework to analyse and assess the aggregate risk as a result of failure of the supporting infrastructure.

WP4 outputs

- Investigate the use of a number of complex systems models with respect to their application to risk assessment in flood event management;
- To outline requirements for complex systems models of the flood event management system.

WPs 1, 2, 3 and 4 have stand-alone reports produced for them in the form of Annexes. These reports should be consulted if the reader wishes to obtain more detailed information of the methods detailed in this report, and further justification as to why they were considered appropriate to analyse the Environment Agency's FIM system.

WP5 outputs

- Review international sources on risk management that are useful to FIM;
- Identify recommendations for managing risk effectively across the FIM process, together with a risk assessment framework.

The report produced as part of WP5 details the conceptual risk assessment framework to assess 'weak links' in the FIM process from detection through to warning and response.

The Environment Agency assembled a team led by HR Wallingford Ltd to undertake the work. The responsibilities of the team were as follows:

WP0 led by HR Wallingford Ltd
WP1 led by Flood Hazard Research Centre at Middlesex University
WP2 led by RM Consultants
WP3 led by the Water and Engineering Development Centre at Loughborough University
WP4 led by Dione Complex Systems
WP5 led by HR Wallingford Ltd
WP6 led by HR Wallingford Ltd

The organisation of the WPs is shown in *Figure 1.1*.

All the WPs were carried out in parallel. The work carried out in WP1, WP2 and WP3 did overlap to some extent. This was intentional, as it provided an opportunity for different project partners to take different views of the same aspects of the problem. It also helped to ensure that a diversity of possible approaches was considered.

It is important to note that FIM systems and procedures are complex. The time available to the project team to undertake the research part of the project was as follows:

HR Wallingford Ltd:	23 days
Flood Hazard Research Centre:	16 days
RM Consultants:	18 days
Loughborough University:	17 days
Dione Complex Systems:	24 days

The limited time available to project teams did not allow a comprehensive data gathering or model development exercise to be attempted. However, it did allow the project teams to look at what data are available, what the user needs are and to propose what types of risk management frameworks and models would be sensible to develop in Phase 2.

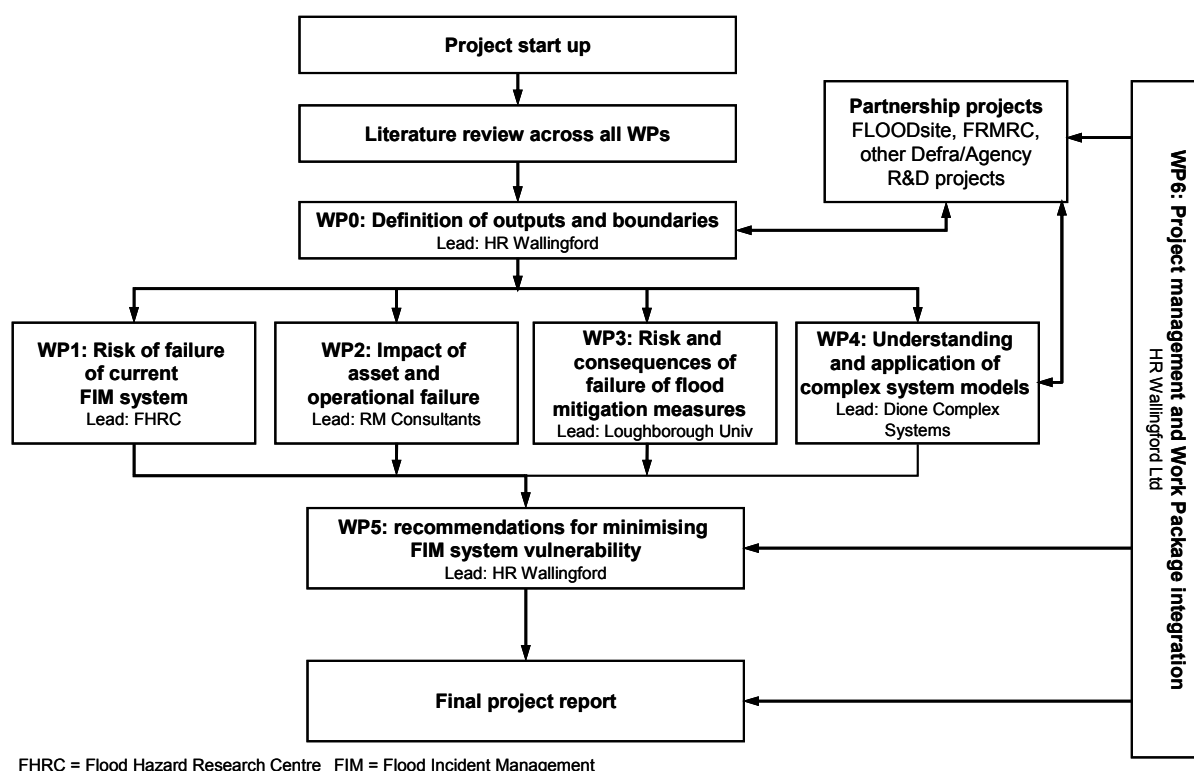


Figure 1.1 Organisation of the project.

1.4 Work package reports

The output, boundary and definitions report (WP0) was produced in January 2006. It should be stressed that this report covers WP5. The key objective of this report is to detail a possible conceptual framework of tiered risk that could be used to assess the ‘weak’ links in the FIM process from detection through to warning.

This report does not provide a summary of all the work carried out in WPs 1, 2, 3 and 4. Stand-alone reports have been produced for these WPs. However, this report does draw together methods that were researched in WPs 1, 2, 3 and 4 and are appropriate to a risk assessment framework for FIM.

1.5 Structure of the report

This report is structured as follows:

- Chapter 1 covers the background to FIM in England and Wales and the Environment Agency FIM process map;
- Chapter 2 outlines the development of a framework for risk assessment in FIM;
- Chapter 3 details the development of performance indicators for the FIM process;
- Chapter 4 outlines tools for use in the risk assessment framework for FIM;
- Chapter 5 provides conclusions and recommendations.

There are also four Annexes that can be read as stand-alone reports that accompany this document:

- Annex 1 details what is meant by ‘failure’ of the FIM process and the development of performance indicators;
- Annex 2 covers the impacts of the failure of flood defence assets on the FIM process;
- Annex 3 provides a method for assessing the interdependencies and the effect of ‘failure’ of the supporting infrastructure (for example, telecommunications networks, transport networks) on the FIM process;
- Annex 4 reviews complex system models and their application to the FIM process.

1.6 Links to other research projects

A number of current Research and Development projects are relevant to the work carried out in this project. The most relevant projects are:

- FLOODsite;
- a project to scope the development and implementation of flood and coastal risk models.

1.6.1 FLOODsite

FLOODsite is an integrated research project on flood risk management funded by the European Community (EC). The main objective of the project is to provide an integrated framework for flood risk management from operational to strategic planning time horizons. The project will deliver:

- an integrated, European methodology for flood risk analysis and management;
- a consistent approach to the whole system, which comprises natural hazard, socio-economic vulnerability and natural ecological and human cultural values;
- a consistent approach to the cause of flooding from rivers, estuaries and the sea;
- a framework for integrated flood risk management, including:
 - FIM (early warning, evacuation and emergency response);
 - post-event activities (review and regeneration);
 - integration with and advancement from other EC and national research.

A number of tasks under FLOODsite have close links to the research being undertaken by the Environment Agency. This includes Sub-theme 2.2 of FLOODsite, which is carrying out research into flood event measures. Three primary tasks are relevant to this research project:

- Task 15 Radar and satellite observation of storm rainfall for flash-flood forecasting in small- and medium-size basins;
- Task 16 Real-time guidance for flash-flood risk management;
- Task 17 Emergency flood management – evacuation planning.

During the past five years a number of extreme flood events have occurred in countries across Europe. These events have tested existing water authority practices to the limit. Lessons have been learnt during these events, but are not widely disseminated. Theme 2.2 will intensify research into evacuation schemes. During a flood event, important activities of the management role are to identify the communities at risk, update evacuation plans and maintain access for rescue services. These activities can significantly mitigate the impact of severe floods on the people and the goods at risk. This requires a trans-disciplinary approach, in which technical science and a socio-economic geographical approach must be appropriately linked. Applying up-to-date data on demographics and infrastructure

(geographical information systems (GIS) analysis) is essential to develop evacuation schemes that effectively prevent casualties among people.

Task 17 of the EC sixth framework project FLOODsite focuses on evacuation modelling and its place in FIM. Evacuation is a process by which people are moved from a place where this is immediate or anticipated danger to a place of safety, offered temporary welfare facilities and enabled to return to their normal activities (or to make suitable alternative arrangements) when the threat to their safety has gone. The emergency services and other public service organisations have key roles to ensure that an evacuation is effective, safe, and comfortable for the people involved, and that they are given appropriate support to cope with any short-term or long-term impacts that may arise.

A review of the evacuation techniques used in flood incidents under FLOODsite indicated that:

- The evacuation is not a stand-alone incident. The nature and effects of the flood define the parameters of the evacuation.
- The evacuation is not just a sub-set of the response to the flood. Most of the evacuation activities proceed independently of the direct response to managing the flood risk.
- The evacuation is not a single, unified activity. It is made up of many individual activities and groups of activities, undertaken by a wide range of organisations.

The work carried out as part of Task 17 in FLOODsite was used to inform the research carried out under this project.

Work carried out under Theme 3 of FLOODsite, which is related to frameworks for technological integration, is also of relevance to this research. Task 19 of Theme 3 of FLOODsite concentrates on producing a decision support framework for planning FIM. The first step in considering the needs of planners for FIM is to identify the physical constraints within which they have to make their specific decisions. This task will:

- link models and related procedures to support emergency management planning and practice;
- provide an end-to-end modelling framework that spans from hazard (for example, precipitation, storm) forecasts to evacuation planning tools embedded in an open modelling platform;
- use evacuation modules to optimise safe-escape logistics to secure evacuation in case of disaster.

The initial work carried out under Task 19 of FLOODsite was used to inform the work carried out under this research project.

1.6.2 Scoping the development and implementation of flood and coastal risk models (SC50065)

The Department of Environment, Food and Rural Affairs (Defra) and Environment Agency research project SC50065 is currently scoping the development and implementation of flood and coastal risk models. The draft copy of this scoping study makes suggestions regarding risk-based FIM.

1.6.2.1 With regards to pre-flood incident planning –

Within the context of pre-event planning, strategy planner and flood incident managers 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 with the Thames Estuary 2100 team, who use the modelling decision support framework (MDSF) to

identify critical receptor hot-spots to aid the development of incident response plans at strategy planning levels. The tiered framework outlined in this report will fit in with some of the tools likely to be developed here.

1.6.2.2 With regards to real-time forecasting and response –

At present, flood warnings are largely issued solely on the basis of predictions of source events. It should be possible and is 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. This understanding is needed to inform decisions about the issue flood warnings, erection of temporary and demountable defences and recommendations to emergency services for evacuations. This progressive level of forecasting, depending upon the level of risk, is shown in *Figure 1.2*.

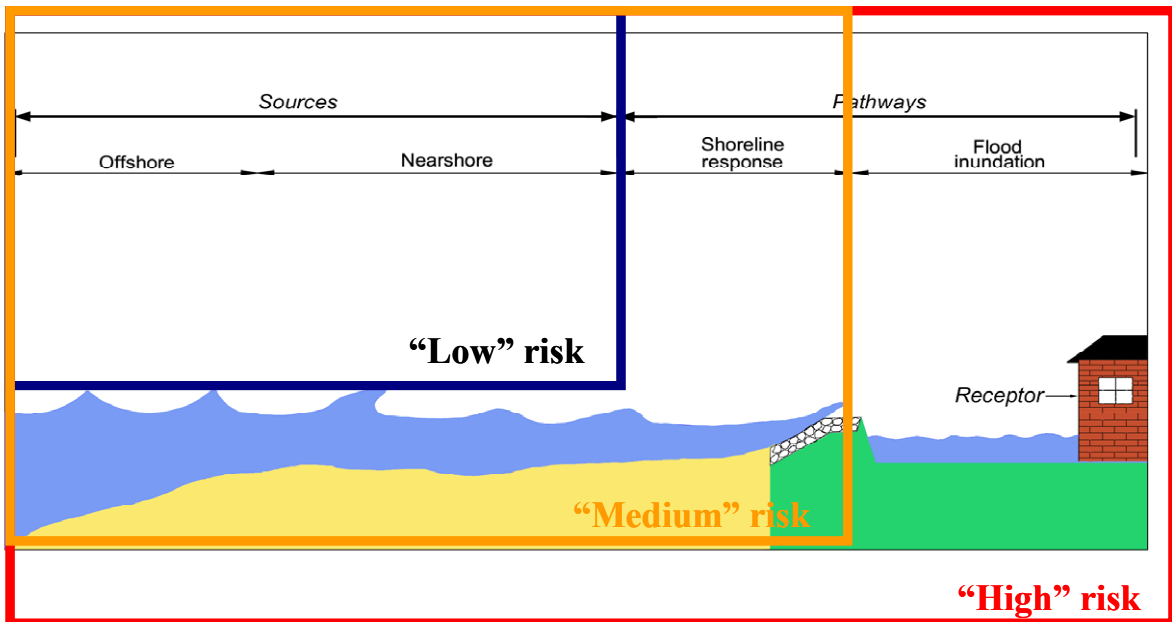


Figure 1.2 Progressive inclusion of sources, pathways and receptors based on the level of risk.

1.7 What is a flood incident?

It is important to be clear about what is meant by a flood incident. Flood incidents vary in scale and impact from the low-impact flooding of an unpopulated floodplain to severe flooding of towns and cities. It is difficult to classify flooding, as each incident and location is different. Among other things, managers of a flood incident have to:

- plan for floods;
- communicate the risk of flooding;
- detect flooding;
- forecast flooding;
- issue flood warnings;
- provide information on flooding;
- respond to flooding.

A major flood incident involves flooding of a significant number of properties or significant disruption to key parts of the infrastructure. It also requires the implementation of special arrangements by the emergency services and local authorities for one or more of the following:

- mobilisation of the emergency services and supporting organisations to reduce the threat of death, serious injury or homelessness for a large number of people;
- handling large numbers of enquiries from the public and the media;
- organising the rescue, transport and care of a large number of casualties and evacuees.

In the simplest case this might be a flood incident exemplified by the Boscastle flood in August 2004 (that is, an event narrowly defined by a single watercourse and a single settlement). In the most complex case this might include a region-wide flood that covers the whole of East Anglia, in which tidal and fluvial flooding are both extensive and affect many rivers, many coastal zones and numerous settlements of various sizes.

A very severe, region-wide flood incident is capable of overwhelming response capacities and could lead, in some circumstances, to unusual impacts such as:

- a temporary breakdown of banking facilities for an appreciable number of people;
- the possible temporary failure of food deliveries and large-scale, temporary homelessness;
- other problems, such as the homes and families of Environment Agency and other personnel involved in the flood emergency response becoming victims of the flood or its effects on infrastructure.

1.8 Flood incident management in England and Wales

1.8.1 Historical record of flood incident management in the UK

The most severe floods in the UK were in 1947, 1953, 1998 and 2000. Using the indicators developed in Chapter 3 of this report the FIM could be classified as ranging from 'poor' in some cases to 'good' in others. Appendix 1 of the WP1 report provides a full overview of FIM in the UK, which is summarised here.

Snow, ice and rain caused the 1947 floods. Many rivers achieved record levels, often not since exceeded (Gardner 1947, Rhodes 1947). Thousands of homes, businesses and industries were damaged to an estimated cost of £12 million (at 1948 prices; Barker 1948, Pollard 1978). The presence of war-time military meant a large standing army helped with evacuation, and it appears that a spirit of defiance ensured the event was by no means a disaster. Increased investment in structural engineering approaches to flood protection was the dominant long-term policy response (Purseglove 1988).

In the 1953 East Coast floods approximately 24,000 houses were flooded, with 450 destroyed (Grieve 1959). Over 32,000 people were evacuated and 160,000 acres of agricultural land were flooded, with 46,000 cattle lost (*Hansard* 1953, Vol. 511, pp. 1459-1460, McCarthy 2003). The damages totalled approximately £50 million at 1953 prices (*Hansard* 1953, Vol. 511, pp. 1466-1467) – approximately £5 billion at today's costs. The official loss of life is 307, but Kelman (2003) suggests a range up to 313. There was no warning (*Times Newspaper* 1953) and the flooding occurred after dark. Oddly, the Cabinet meeting the day after did not mention the flood at all!

In 1998 fluvial floods affected a large swathe of central England and Wales over the Easter holiday period. These often matched or exceeded the 1947 event (Bye and Horner 1998a, 1998b, Saunders 1998). They caused the loss of five lives and £300 million damage to approximately 4500 houses, 522 industrial premises and 2000 caravans (1998 prices). Largely owing to the lack of a flood warning, the

Environment Agency, formed just two years earlier, was heavily criticised (BBC News Online 1998; Environment Agency 1998a). Its Board moved rapidly to establish an Independent Review Team, chaired by Peter Bye, to investigate the Environment Agency's performance (Bye and Horner 1998c, 1998d). Better incident management was a prime recommendation.

The floods in Autumn 2000 were unprecedented in their geographical scale and repetitive nature (Defra, 2001a, 2001b, Environment Agency 2001a). *Figure 1.3* illustrates the cost of the autumn 2000 floods prior, during and after the flood incident. Approximately 11,000 properties were flooded at 827 locations, but at only 20 of these were more than 100 properties affected. However, some 11,000 people were evacuated, train services were suspended and the East Coast Mainline was closed for nearly a week (Environment Agency 2001a). The financial losses were approximately £1.48 billion (Penning-Rowse *et al.* 2002). The warning system was perceived to have operated well (Environment Agency 2005b) and the sheer timescale of the flood meant that the event was 'managed' such that damage and disruption were kept to a minimum (although they were still large).

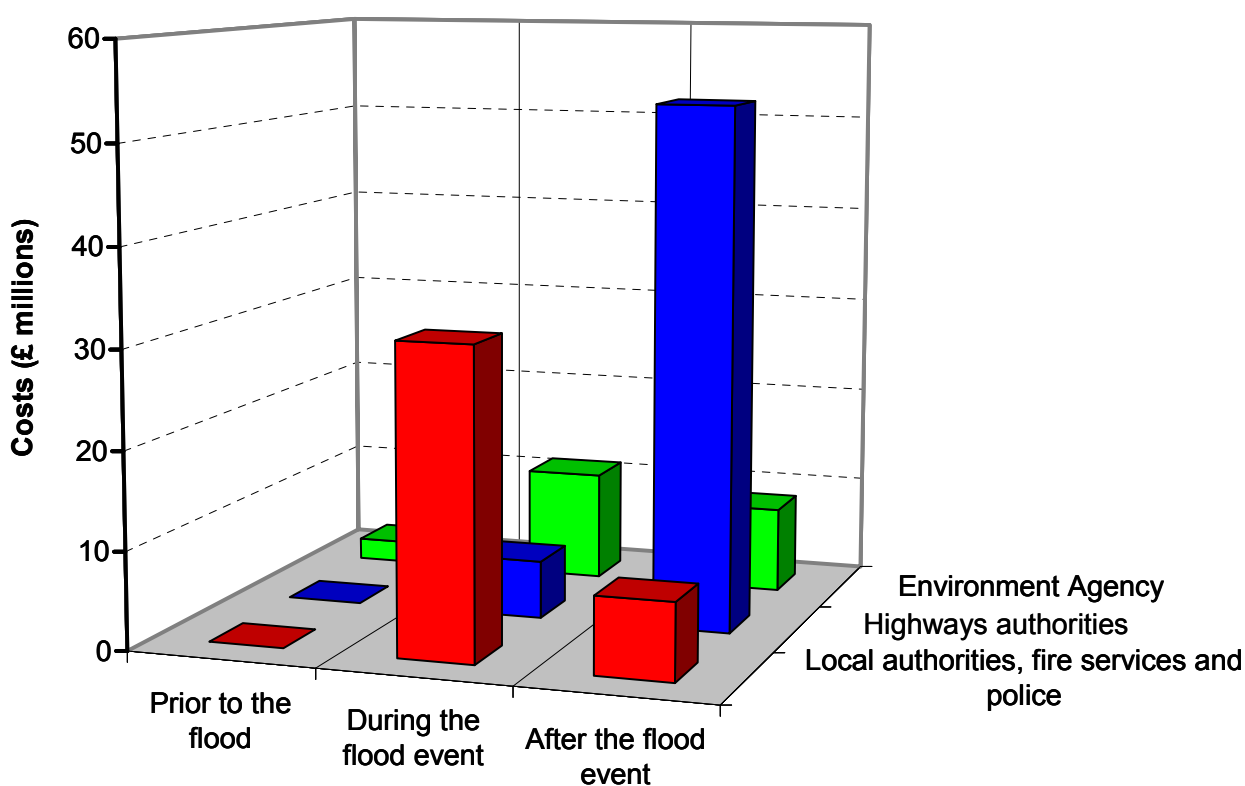


Figure 1.3 Costs of the autumn 2000 floods.

1.8.2 Consultation with stakeholders

In November 2005 a one-day workshop on FIM was held at HR Wallingford. Some 50 people from the Environment Agency and other organisations (for example, emergency planners from local authorities) that play a key part in FIM attended the workshop. In the afternoon the stakeholders were divided into three subgroups to deal with the following issues:

- Group 1 business and organisation issues;
- Group 2 staff, operation and assets;
- Group 3 information technology (IT) systems, tools and models.

Each group was asked to identify:

1. factors that could lead to 'failure' of the FIM process;
2. what work has been done to date to manage the risks in the FIM process, both within and outside the Environment Agency;
3. methods to reduce risk in the process of FIM.

The results of the consultation are summarised below.

1.8.2.1 Factors that could lead to a 'failure' in the flood incident management process

The three groups identified the main factors that could lead to a 'failure' in the FIM process:

- 'failures' in communications between the Environment Agency and other partners in the FIM process;
- availability of operational delivery resources to meet demand;
- ineffective debriefing of staff;
- failure of road transport, road blockages and traffic delays;
- lack of knowledge about assets failure and flood-risk areas;
- staff without the correct competencies and/or inexperienced staff sometimes led to a failure to understand their incident management roles.

The most consistently mentioned factor was that breakdown in communications, both internal with the Environment Agency and external with other emergency response groups, posed the greatest risk to 'failure' in the FIM process.

1.8.2.2 Identification of the work undertaken to manage the risks in the flood incident management process

A summary of work recently undertaken by the Environment Agency to manage the risk in FIM was also made. Recent work completed by the Environment Agency includes:

- 1 Process mapping for FIM has been produced. An example of this is shown in *Figure 1.4*. This has allowed the Environment Agency's FIM process to be well defined and the various procedures and work instructions to be linked to the various stages of the process.
- 2 Contingency plans have been developed (for example, including the use of loud hailer systems if other means fail, displacement of incident rooms).
- 3 The Flood Warnings Direct has been implemented, which means that in future the dissemination of flood warnings will be improved;
- 4 The quality and quantity of staff training and exercises in FIM has improved in the past few years.

1.8.2.3 Methods that could risk reduction in risk in the flood incident management process

The comments made by the three groups can be summarised as:

- a more structured approach to FIM is needed;
- systems and processes with more resilience, more redundancy and more support are needed;

- a 'total systems model' is required to compare and/or standardise performance.

The main conclusion was that there needs to be a comprehensive, systematic method to assess the risk in the FIM process, and that there is a need for an overall risk assessment framework to:

- assess the weak links in this process;
- prioritise the appropriate mitigation measures to reduce the risks in this process.

1.8.3 Summary of review of literature on flood incident management in the UK

A review of the vast array of literature on FIM indicated that:

- research on the effectiveness of FIM is sparse;
- there is often little quantitative data available on the FIM process;
- the record of FIM in major floods on the UK is mixed;
- the performance of the FIM process is rarely measured;
- the consequences that occur because of the 'underperformance' of the FIM process are rarely quantified;
- communication effectiveness is one of the keys to good FIM, but communication of risk is inherently difficult;
- good incident management is about influencing human behaviour, which is not easy;
- good incident management is costly;
- there is little Government guidance on what constitutes 'good incident management' (other than saving lives).

For more details of FIM in the UK, consult the WP1 report.

1.8.4 Environment Agency flood incident management process map

The Environment Agency has developed a 'process map' that shows how their FIM process operates and the roles of Environment Agency staff. The process map was created with the assumption that the National Flood Forecasting System (NFFS) and Flood Warning Direct System (FWD) would be implemented. The tiered process maps show how all the activities fit together. The FIM process is a series of 'nested' process diagrams, the top level of which is shown in *Figure 1.4*.

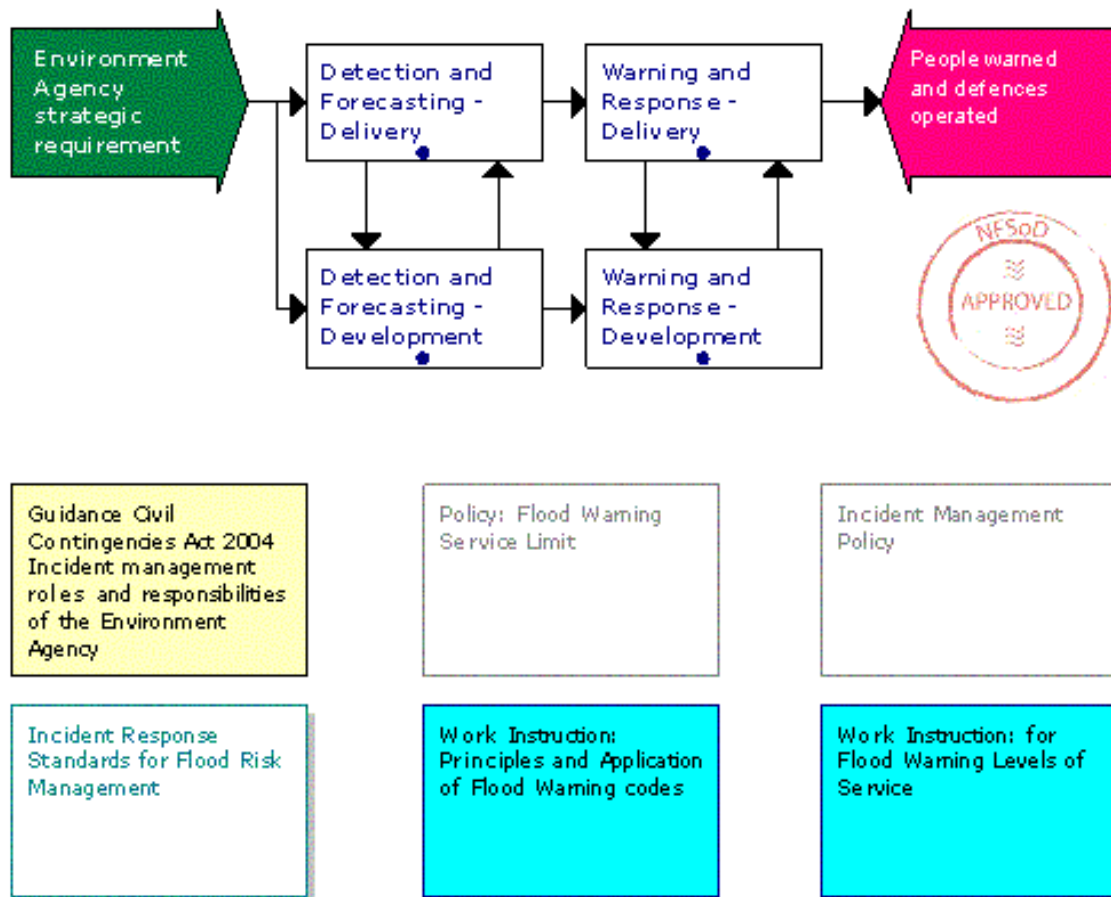


Figure 1.4 Environment Agency's end-to-end process diagram for flood incident management.

2 Development of a framework for risk assessment in flood incident management

2.1 Background

The information management method proposed to develop the framework is known as the Business Elements Method, developed at the London School of Economics, in conjunction with HR Wallingford. This method is able to encompass all aspects of the work, including supply chains, roles and responsibilities, monitoring and control procedures, as well as data handling and assessment methods. The method incorporates sound tools and techniques that have been applied successfully in many settings.

At the core of the framework is a generic approach that can be applied at all decision scales. This was based on the Department of the Environment, Transport and Regions (DETR) report *Guidelines for Environmental Risk Assessment and Management*, which is generally recognised within the UK as the best approach to assessing and managing environmental risk. This approach has already been adopted in the Flood and Coastal Defence Project Appraisal Guidance (FCDPAG), refined by the Risk Assessment for Strategic Planning (RASP) methodology and used for the Flood Risk Assessment Guidance for New Development. As a consequence, the basis of the framework is wholly consistent with current Defra and Environment Agency practices. The WP2 report details an alternative risk assessment framework that has been applied to active flood defence assets (for example, barrier and gates). More details of this framework are given in the WP2 report.

2.2 Structure of the generic approach risk assessment framework

The generic approach can be applied at all decision-making levels and risk assessment scales, either by those who undertake the decision making or those who undertake the assessments. A single approach is required, because the decision-making and assessment processes are iterative. It is important for assessments to be designed to suit the decision-making needs.

The generic approach enables those who:

- undertake assessments to determine how to carry out an appropriate assessment;
- review assessments to determine whether the assessment has been carried out appropriately;
- undertake the decision making to use the results of the assessment appropriately;
- review the decision making to determine whether the decision makers have used the results of the assessment appropriately.

Figure 2.1 illustrates the framework for the risk assessment process recommended by Defra for projects. This has been adapted slightly to provide a quantitative risk-assessment step in Tier 1, rather than a qualitative one.

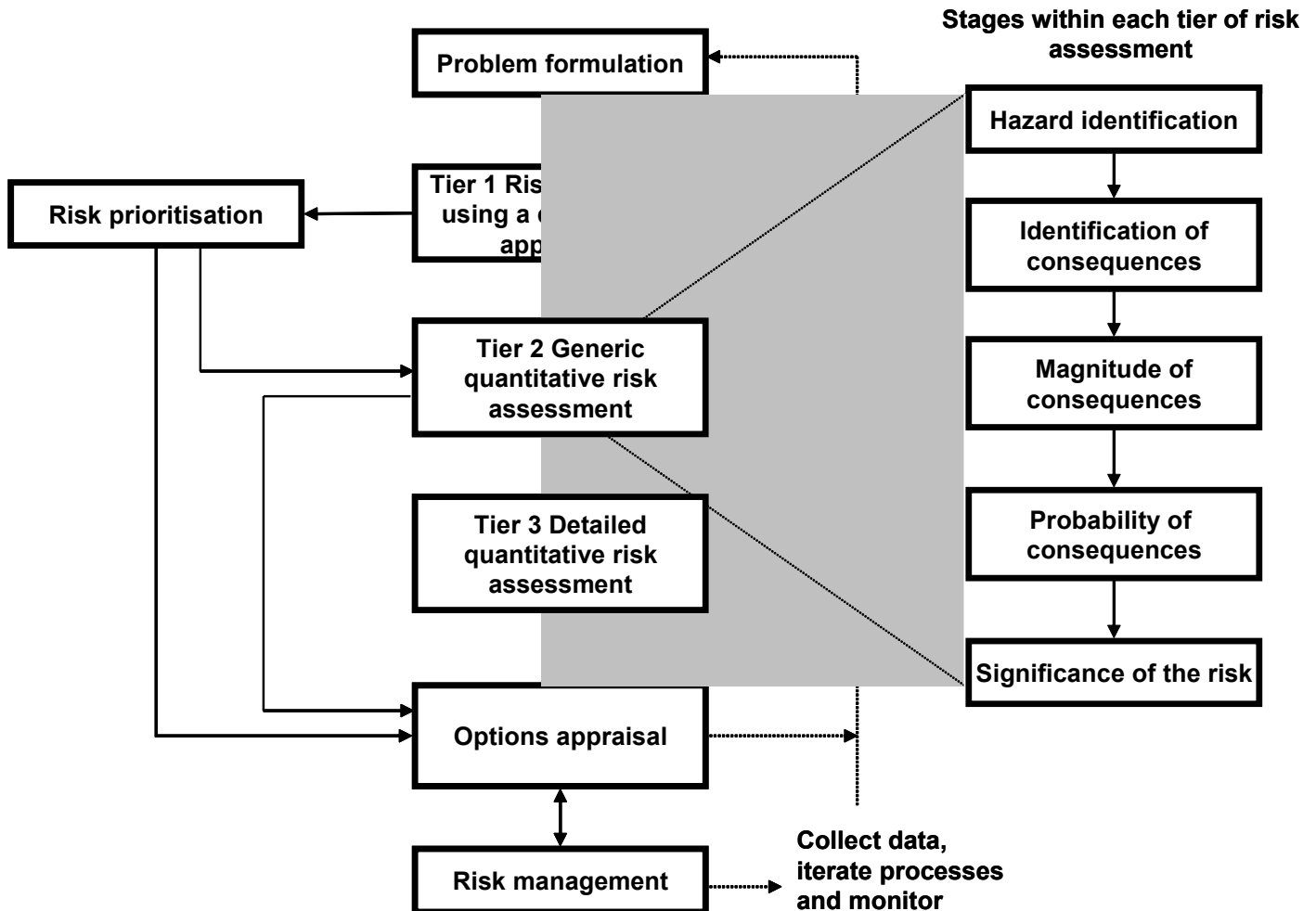


Figure 2.1 Framework for environmental risk assessment.

This approach has been developed into a series of simple, user-friendly processes, which can be applied to any type of assessment of flood risk. There are five processes:

- Process 1 – Problem formulation
- Process 2 – Tier 1 Risk screening using a quantitative approach
- Process 3 – Tier 2 Generic quantitative risk assessment
- Process 4 – Tier 3 Detailed quantitative risk assessment
- Process 5 – Risk management

Whether undertaking a decision-making exercise based on the results of an assessment of flood risk or undertaking the assessment itself, it is necessary to understand what is trying to be achieved and the boundaries being worked within. This will help to achieve the following:

- identification of FIM objectives and sustainability objectives, which enables more comprehensive decision making to be undertaken and, in turn, should result in better 'value for money' solutions;

- early commitment from relevant groups, which reduces the likelihood of delays at later stages;
- recognition that assessments are undertaken with limited time and budgets, but by careful planning and an appropriately focused assessment, optimum decisions can still be made.

The purpose of undertaking a tiered approach is to allow proportionate effort to be applied, based on a number of factors, including:

- decision-making requirements;
- scale of the risk;
- degree of uncertainty;
- size of the catchment;
- unique characteristics of the catchment.

All assessments should undertake a ‘broad-brush’ quantitative assessment (Level 1). The baseline conditions used to decide whether to proceed to the next level of detail are determined during Process 1 – Problem formulation, although these may need refining as the risks associated with the FIM system for a particular catchment are better understood.

The monitoring and review process is an integral part of FIM and is key to determining and ensuring the performance of the FIM system so that the Environment Agency’s targets are met. At the present time, this process is perhaps more aspirational than current practice, but it should be encouraged as part of a best-practice approach.

It is important that any risk assessment framework has the following characteristics:

- be simple to construct;
- be adaptable;
- does not require specialist expertise to master and communicate.

2.3 Problem formulation

When undertaking a risk assessment for the FIM process it is necessary to formulate the problem clearly and concisely. A proposed framework for this should define the:

- intention of the risk assessment, including the groups to be consulted and the objectives of the assessment;
- scale at which the risk assessment is going to be carried out, that is:
 - national,
 - regional,
 - catchment,
 - sub-catchment,
 - local;
- temporal and financial constraints;
- staff resources available;
- performance indicators to be used.

2.4 Tiered risk assessment

2.4.1 Features of a tiered risk assessment

A tiered risk assessment has the following:

- is set up in a number of sequential steps of increased complexity and effort;
- specifies decision criteria for each step;
- involves evaluating whether or not the next step of assessment should be undertaken based on these criteria.

Tiered assessments involve carefully planned iteration. However, the iteration is not always planned at the start of the assessment. New information or a need to re-evaluate something can trigger it, which could happen at any point in the risk assessment.

It is important that a tiered risk assessment is carried out and that the following questions are answered:

- Have risks been screened?
- Have risks been prioritised?
- Has an intermediate assessment been carried out, if required?
- Has a detailed assessment been carried out, if required?

With regards to the risk assessment undertaken at each tier of the framework, it is important that the following are taken into account:

- Have the hazards been identified?
- Have the consequences been identified?
- Have the magnitudes of consequences been determined?
- Have the probabilities of the consequences been determined?
- Has the significance of the risk been determined?

2.4.2 Levels of risk assessment

For a 'broad-brush' assessment (that is, Level 1 risk assessment), the analysis will be based on existing information, which will be both quantitative and qualitative. For a complex system, such as the Environment Agency FIM process, a high-level quantitative assessment of the components of the system is required.

For an intermediate assessment (that is, Level 2 risk assessment) the analysis usually becomes more involved. However, the degree of uncertainty in either the input data or results is likely to be reduced. The prioritisation process may result in only some of the risks in the FIM process being considered at the Tier 2 or Tier 3 level as result of the screen process. A detailed assessment will involve a detailed quantitative analysis, to reduce the degree of uncertainty as much as possible. This could involve extensive data collection.

In seeking to understand such a diverse behaviour, risk analysts have recognised the importance of 'tiered' approaches as a way to manage the complexity in many risk issues. This means to carry analysis to a level of detail appropriate to the decision and to carry out analysis consistent with the level of data and/or information available (Defra and the Environment Agency 2003b). In a well-designed risk analysis system, there should be consistency between these different levels of analysis, even though the issues considered

may well be different. As the tier of the assessment descends the risk assessment methodologies become more specific to a particular problem or decision as the level of detail increases (Defra and the Environment Agency 2003b). A possible tiered approach to risk assessment that could be applied to the FIM process is shown in *Figure 2.1*.

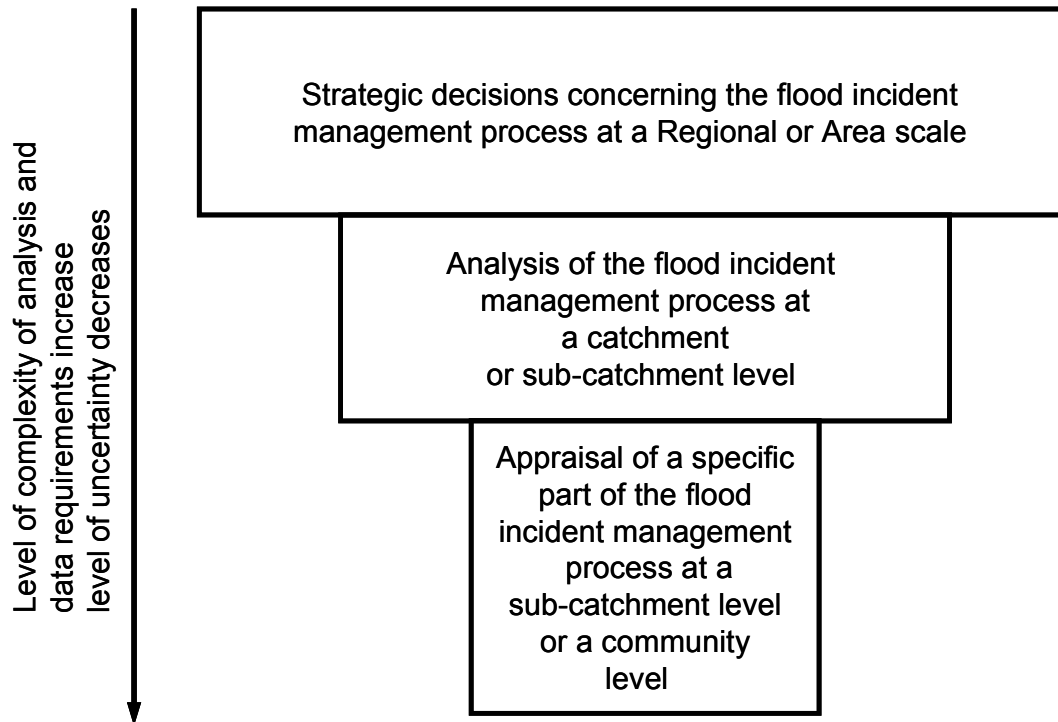


Figure 2.1 Possible tiered approach to risk assessment in the flood incident management process.

In WPs 1, 2, 3 and 4 a number of tools and models are reviewed with respect to risk assessment of the FIM process. Many of the tools reviewed have been applied to assess risk in fields other than flood risk and FIM (for example, air traffic management, financial institutions). However, many of these tools are well suited to assessing the 'weak links' in the FIM process.

For example, air traffic management has 'technical', 'human' and 'procedural' aspects to it, similar to FIM. In air traffic management systems the qualitative risk assessment starts with a systematic gathering of information about 'nominal' and 'non-nominal' behaviour of the air traffic management system considered, concerning, for example, the human roles, the procedures and the technical systems. All relevant experts are involved in this part. To gather 'non-nominal' information, explicit use is made of structured hazard-identification sessions with a variety of experts and hazard databases. The resulting list of identified potential hazards is subsequently analysed using established qualitative hazard analysis techniques to identify the safety-critical encounter scenarios and associated hazards, and to select one or more of those safety-critical encounter scenarios.

Risk assessment tools and techniques provide partial answers to these questions through reasonable quantitative estimates of the linkages in causal chains that lead to an accident involving human error. Quantitative models, however, require very specific data that enable the description of the phenomena and relationships of interest. The circularity of these statements is important: risk analysis is used to predict the potential for accidents through

human error, but knowledge of the linkages between human error and accidents is essential to building risk models. Hence, to assess risk adequately in the Environment Agency's FIM system, it is crucial to have adequate information available concerning why the system has failed in the past. Chapter 3 of this report details the tools that could be employed in a tiered risk assessment for the FIM process.

3 Tools for use in the flood incident management risk assessment framework

3.1 Introduction

As part of this project a number of tools were examined for use in a framework for risk assessment in FIM. These tools are fully detailed in Annexes 1, 2, 3 and 4 that accompany this report. This chapter describes the tools that could be used to undertake a risk assessment of the complete FIM process using the tiered risk assessment approach described in Chapter 2.

Before outlining these tools it is important to recognise that the FIM process from detection to response is a complex system. Typical features of complex systems are:

- (i) **Relationships can be non-linear.** In practical terms, this means a small perturbation may cause a large effect, a proportional effect or even no effect at all. In linear systems, the effect is always directly proportional to the cause.
- (ii) **Relationships contain feedback loops.** These can be both negative (damping) and positive (amplifying) feedback. The effects of an element's behaviour are fed back in such a way that the element itself is altered.
- (iii) **Complex systems are usually 'open'.** That is, the system is not self-contained in that it has no fixed boundaries.
- (iv) **Complex systems have a history.** As complex systems are dynamic systems, they change over time, and hence prior states may have an influence on present states.
- (v) **Complex systems may be nested.** This means the components of a complex system may themselves be complex systems, as is the case in the FIM process.
- (vi) **The boundaries are difficult to determine.** It can be difficult to determine the boundaries of a complex system.

The FIM process exhibits all of the above features and thus can be considered a complex system. Also, our knowledge of the behaviour of the complete FIM is incomplete. Other features of the FIM process are:

- Spatial and temporal variations of flood incidents vary dramatically.
- Descriptions are often based on sparse and/or incomplete data. Quantitative information on many elements of the FIM process is sparse, especially with regards to many of the less 'technical' elements (for example, organisational, resourcing and health and safety issues).
- There are many different groups with various, and sometimes conflicting, values and objectives.

3.2 Introduction to the tiered risk assessment for flood incident management

The tools introduced in this chapter are *pre-incident* planning tools. That is, the tiered approach and the tools involved in its use are employed as planning tools to minimise the 'breakdowns' in the flood incident process prior to a flood occurring, with the objective to minimise risk during a flood incident.

The risk assessment framework should have the following characteristics:

- be simple to construct;
- adaptable;
- not require specialist expertise to master and communicate.

The performance indicators used to express the risk (for example, forecasting, economic damage, injuries, etc.) may vary depending on the level of the analysis and the part of the FIM process being analysed.

It is recommended that for risk assessment in FIM a three-tier approach be used that is similar to the approach taken to evaluate risk in flood and coastal defences (Defra and Environment Agency 2003b). *Table 3.1* details the three-tiered risk assessment framework. The various levels of the tiered framework are given in Sections 3.3, 3.4 and 3.5.

Table 3.1 Possible levels in a tiered risk assessment for flood incident management.

Level	Decision to inform	Data sources	Methodologies
Tier 1 – High level	Flood incident management strategies at regional or area level Risk screening and prioritisation of risk assessment at Tier 2 and Tier 3 levels	Previous flood incidents Information collected from stakeholders responsible for flood incident management	Performance assessment framework Analytic Hierarchy Process
Tier 2 – Intermediate	Appraisal of the flood incident management process at a catchment or sub-catchment level	Previous flood incidents Information collected from groups responsible for flood incident management Probabilities of failure of flood defence and other assets (for example, supporting infrastructure such as telecommunications)	Analytic Hierarchy Process Use of Bayesian networks
Tier 3 – Detailed	Analysis of a particular element of the flood incident management (for example, response for a particular area) process to establish the 'weak links' and their associated consequences	All the parameters required to describe the interdependence between the various elements	Use of Bayesian networks

3.3 Tier 1 tool – Risk screening using a quantitative approach

Numerous techniques are available for screening risk. The objective of a risk screening technique is to filter out FIM processes that are not significant in the overall decision-making process. To apply such 'broad-brush' techniques effectively it is important that groups with a good understanding of the FIM process implement them. Methods to screen risk are, by their nature, approximate and hence should be designed to be conservative so that important issues are not rejected at an early stage. In some cases, risk screening may simply be a matter of identifying whether a particular risk could arise (for example, whether there is a possibility of harm as a result of 'failure' in the FIM process and the vulnerability of the likely receptor). However, given the complexity of this process, in many cases this will not be possible.

A number of screening and prioritisation tools can be employed to provide structure to the evaluation of identified risk scenarios. The Tier 1 tools to screen risk concentrate on the following two methods identified in WP1 and WP3:

- (i) The use of performance indicators.
- (ii) Analytic Hierarchy Process (AHP).

3.3.1 The use of performance indicators

3.3.1.1 Background

A performance indicator can be defined as ‘... the well articulated and measurable objectives of a particular project or policy. These may be detailed engineering performance indicators, such as acceptable overtopping rates or rock stability, or more generic indicators such as public satisfaction or other key performance indicators’ (Environment Agency and Defra 2005).

Performance indicators are tools that help to assess what is being achieved. They can also be defined as a numerical measure of the degree to which the objective is being achieved. There is often a tendency for performance indicators to focus on the technical measures of performance (for example, the degree to which information technology (IT) systems cope during a major flood incident) because these are often easy to measure. However, the counter view is that the real measures of FIM are at the later, output end of the processes.

Performance indicators assist us to measure the performance and effectiveness of the FIM system. These indicators reflect the organisational, development, capacity and institutional actions taken to reduce vulnerability and losses, to prepare for a flood and to recover efficiently from incident. The performance indicators provide a qualitative measure of management based on predefined standards that risk management efforts should aim to achieve.

Performance indicators must be transparent, effective, representative and easily understood by Environment Agency staff as well as public policy makers at national and regional level. It is important that application of the evaluation methodology is easy for it to be used periodically, facilitate management risk aggregation and compare regions, catchments and areas.

The main limitation to using performance indicators as tools for risk screening is that they rely on a sufficient level of detail of information being collected during a previous flood incident or training exercise. As noted in Chapter 1, in many cases there is often little quantitative data (or in some cases qualitative information) available on the FIM process.

Choice of performance indicators

A large number of issues surround the choice of performance indicators for FIM. The Environment Agency and other key groups in the FIM process need to have a major input in the choice of these performance indicators as they need to define the desired state of FIM, bearing in mind that ‘perfection’ is not always (or ever) possible. It is therefore important to emphasise outcomes in performance indicators and recognise that it is the processes that drive them. *Figures 3.1* and *3.2* show the performance indicators for a range of elements for the FIM processes and FIM outcomes.

Performance as a matter of perspective and perception to be managed

It is not unusual for the same process or system to be viewed as performing well by some, but poorly by others. Numerous examples confront us each day in the media, or perhaps personally, including speed cameras, the London congestion charge, the prison service, primary care trusts, medical care, weather forecasting and so on. Where some see success, others see failure.

In some cases the debate and views that surround processes or systems become strongly political, which can happen with FIM, though the degree of politicisation that surrounds flood management is very variable. It is not surprising, therefore, to find that the managed response to a flood event is not perceived uniformly by all those involved and observing. This is shown in *Figure 3.3*.

In some cases it may be that the views about the management of a flood incident might vary greatly and may even be polarised. For example, it would be unsatisfactory if, for example, the Environment Agency were satisfied with the performance of a managed flood event when other groups are dissatisfied and overtly critical. Clearly, the Environment Agency needs to consider the perspectives of the principal groups and design performance accordingly to meet the expectations of them. Equally, in considering performance it is important to consider how each principal group forms its perceptions of performance – that is, what are the main factors that will condition the perceptions of performance considering the perspective(s) on a flood incident? These are highlighted in *Table 3.2*.

This is another way to express that many different groups are involved in most flood risk locations and flood events, and that performance is as much a matter of group perception as objective measurement of defined performance parameters. However, if chosen well, the latter can be used to influence the former, which is a line of thinking that should be drawn upon.

Table 3.2 presents the core factors that are important in determining whether a managed flood incident is perceived as being well or poorly managed. These core factors should inform the parameters that will be used to scale and measure FIM performance. Otherwise, there is a distinct risk of a core factor being omitted, which could lead to exposure to criticism that might lead to the performance being perceived as unsatisfactory. In practice, it is important to ‘score well’ on as many core factors as possible to maximise the chances of FIM performance being perceived as successful.

The above thinking suggests a process of FIM that incorporates the following elements:

- management of the flood event – processes and outcomes;
- management of flood event management group’s, including:
 - their expectations prior to flood incidents;
 - the information they receive prior to, during and after a flood incidents.

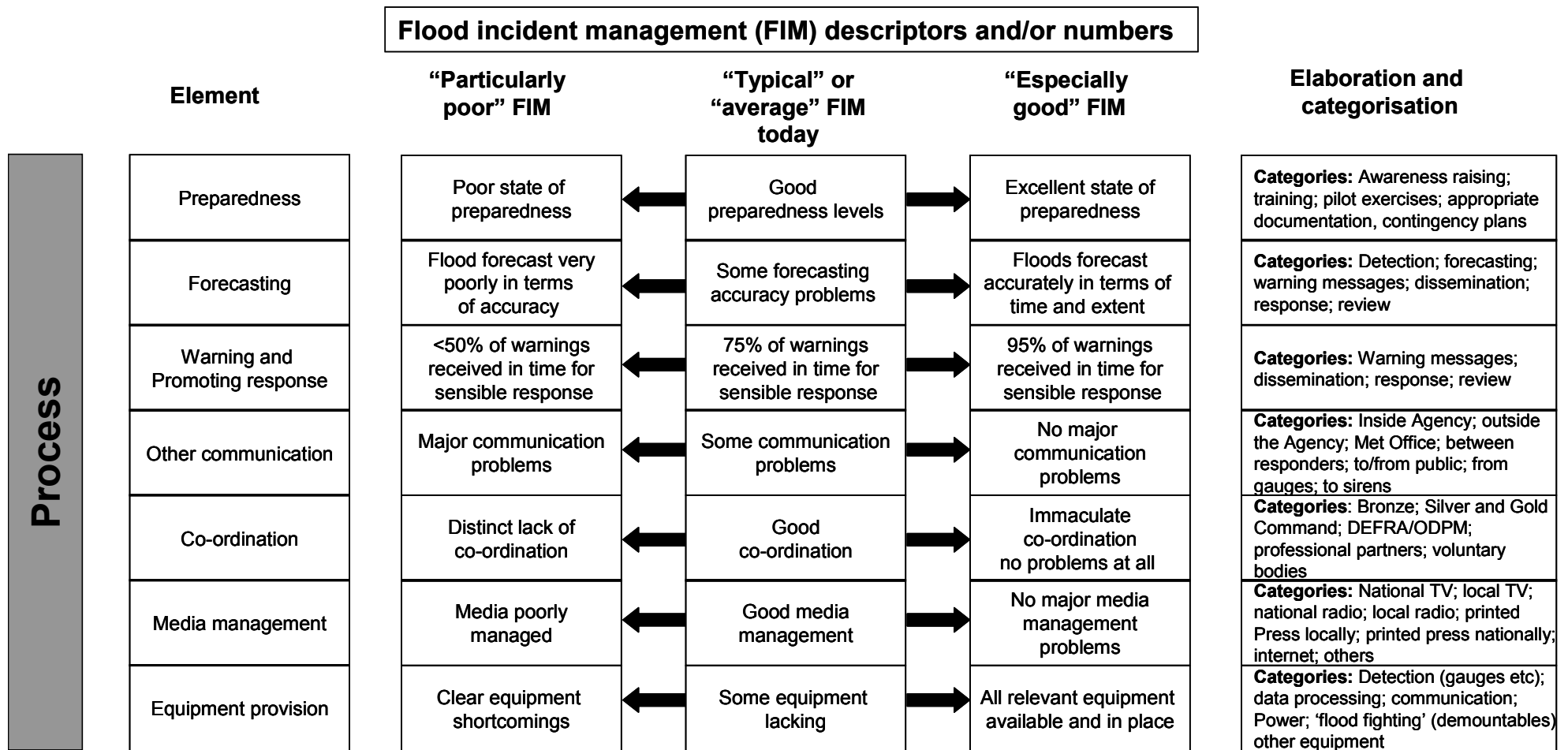


Figure 3.1 A simplified set of descriptors for the flood incident management process.

		Flood incident management (FIM) descriptors and/or numbers			
		“Particularly poor” FIM	“Typical” or “average” FIM today	“Especially good” FIM	Elaboration and categorisation
Outcomes	Element				
	Environmental damage	Unwarranted environmental damage	Minor environmental damage	Negligible environmental damage	Categories: Flora; fauna; landscape; Archaeological remains; others
	Economic damage	Unwarranted property damage	Less than Multi Coloured Manual damage	Much less than Multi Coloured Manual damage	Categories: Residential; non-residential; public buildings; infrastructure damage (utilities); others
	Injuries	Greater than 5	Equal to or greater than one	0	Categories: Immediate and directly flood related; medium term effects (direct and indirect)
	Loss of life	Equal to or greater than one	0	0	Categories: Age; gender; social class; local/visitor; prior health status
	Victim trauma etc	Greater than 25 people affected	Equal to or greater than five people	No people affected	Categories: Age; gender; social class; local/visitor; prior health status
	Reputation of Environment Agency and others	More negative than Positive comments	Less than 33% negative comments	Less than 20% negative comments	Categories: Public nationally; public locally; politically (MPs; DEFRA; ODPM) with professional partners

Figure 3.2 A simplified set of descriptors for the flood incident management outcomes.

Note: The set of descriptors shown in *Figures 3.1* and *3.2* are purely indicative and in some cases need to be established on an area-by-area basis. For example, if an embayment in London were flooded then a figure of only 25 people affected in terms of victim trauma may be considered ‘especially good’ FIM.

Table 3.2 Core factors that influence the perspectives of the principal groups in floods and hence the performance of the flood incident management process and outcomes.

Principal stakeholder	Core factors
Flood victims and residents	<ul style="list-style-type: none"> • Whether anyone died in the flood • Whether or not timely warning was received (flood warning lead time measured as time between receipt of warning and onset of flooding at the property concerned) • Whether or not 'official' timely help was visible and received, before, during and after the event • Amount of damage incurred • Amount of perceived health damage incurred • Degree to which injustice(s) are perceived in causes of flood and the way in which event was managed • Degree to which 'the authorities' were perceived to be well prepared • Flood experience – the history of events and incident management
Local flood action group (LFAG)	<ul style="list-style-type: none"> • Whether or not the issues raised before the flood by the LFAG had been responded to effectively by the authorities • Whether or not the LFAG had been invited to participate in a flood event management rehearsal
Environment Agency	<ul style="list-style-type: none"> • Flood warning lead time provided measured as time between issue of forecast and on-set of flooding • Degree to which the flood forecast was accurate (measured by difference between forecast and actual flood peak and timing) • Degree to which flood routing was accurate
Political representatives	<ul style="list-style-type: none"> • Degree of concern and/or complaints registered with local councillors and Members of Parliament (MPs; measured by mailbag size) • Extent to which issues raised prior to the flood event had been responded to adequately by the authorities • Degree to which wider political issues are raised by the flood event (for example, care of the elderly, availability of flood insurance, spending on emergency services, etc.)
Emergency services and planners	<ul style="list-style-type: none"> • The timeliness and accuracy of the warning received by them • The quality and timeliness of the flow of information received by them and provided by the flood defence agency • The quality and timeliness of the flow of information received by them and provided by emergency services partners, including the police • The degree to which they receive public criticism for circumstances beyond their control (for example, a poor flood forecast)
Researchers and reviewers	<ul style="list-style-type: none"> • Whether lessons learned from other floods have been truly learned – whether improvement in performance can be demonstrated or not • Existence of analysed failings and flaws in flood event management systems • Whether the evidence about the flood event and its management is reassuring or not • What the impacts were – properties affected, at what depths, proportions that received prior warning and that did not; economic damage, number of people affected, deaths, etc. A quantitative evidence assessment

Table 3.2 Core factors that influence the perspectives of the principal groups in floods and hence the performance of the flood incident management process and outcomes.

Broadcast and print media	<ul style="list-style-type: none"> • Whether or not there are other competing and more important news stories shapes the degree of coverage and exposure of the flood event management – largely unpredictable • Size of impact and availability of graphic materials – graphic damage • Evidence of any shortcomings and failures will be pounced upon – for example, lack of coordination, especially where these lead to people being stranded, airlifted, injured, traumatised or killed • Whether or not any of the above groups make critical comments • Reputation of the flood defence agency • Iconic dimensions will be used
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Currently, most of the effort in FIM is targeted to manage the flood incident, but some is made to manage group expectations and the information they receive prior to a flood event. The management of flood incident groups has grown in importance, but now needs to be taken to a new level to shape and manage their perspectives and perceptions of flood events and their management.

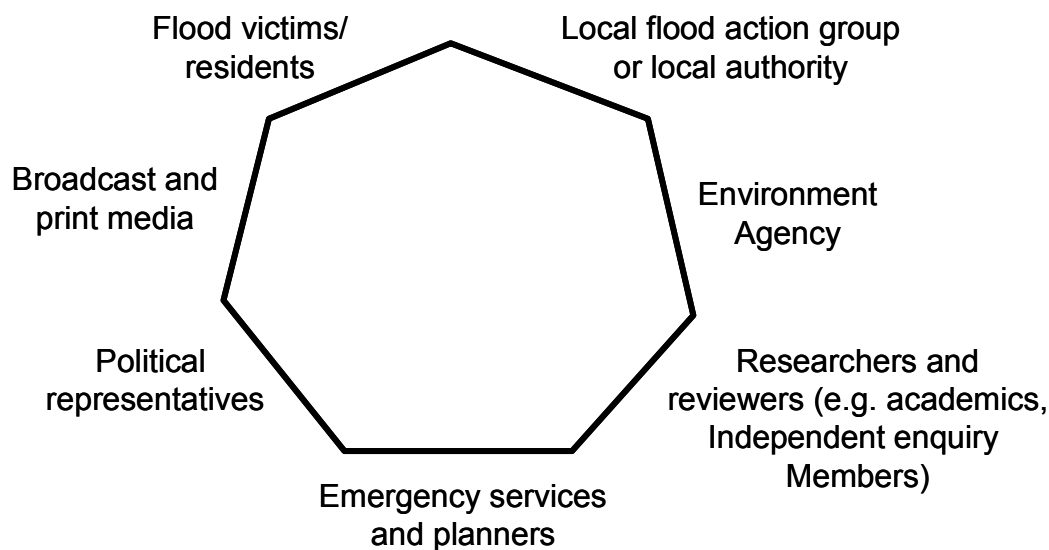


Figure 3.3 Different perspectives on, and perceptions of, the performance of managed flood incidents.

3.4 The use of performance indicators as a Tier 1 risk assessment screening tool

3.4.1 Background

Given that ‘failure’ is too simplistic a concept and ‘performance’ needs to be measured, a multi-criteria framework should be adopted. This means that no single measure can be used to gauge the performance of a FIM system, and that several criteria need to be looked at together. A system is also needed that is simple to understand and operate, given that many different groups are involved and have different perspectives.

An initial proposal for multi-criteria performance indicators (which needs considerable refinement) is shown in *Figure 3.1*. This sees actual performance, as judged by the different criteria, on some continuum, with current performance somewhere in the middle of the range. This implies that performance is better than might be the case, but that we are some way from perfection. The choice of the elements in *Figure 3.1* is not easy, especially given the need for simplicity.

3.4.2 Choice of elements for performance indicators

There is a distinct danger that technical considerations will draw some analysts solely into measuring performance of IT systems, flood forecasting software, etc., but this only tackles part of the problem. The traditional 'flood forecasting and warning' element has been separated into two elements – that is, one element for 'Flood forecasting' and one for 'Flood warning'. This is because these are quite different – the forecasting element is where you may have more 'technical performance issues' and the warning part is where you may have more 'communication performance issues'. The suggested elements for the performance indicators are as follows:

- preparedness;
- forecasting;
- warning and promoting response;
- other communication;
- coordination;
- media management;
- equipment provision;
- possible other categories.

These elements are discussed below.

3.4.3 Preparedness

Preparedness descriptors should gauge the extent to which the target audience is prepared to receive warnings and FIM advice and instructions. Measures should assess the degree to which awareness is raised, the extent of training, the number and dates of training exercises, the availability and appropriateness of documentation (including whether it is up-to-date) and the extent of contingency plans.

3.4.4 Forecasting

Forecasting descriptors could be measured in terms of the flood forecast lead time. The performance categories for flood forecasting could be:

- performance of the hydrometeorological network;
- communication links with respect to hydrometeorological data;
- performance of the NFFS;
- performance of the IT systems (that is, hardware and software other than the NFFS);
- performance of other relevant hardware.

3.4.5 Warning and promoting response

The descriptors could be the percentage of people who receive a flood warning or the flood warning lead time received. The flood warning lead time is different to the flood forecasting

lead time in that you may forecast a flood ten hours in advance, but only get the warning out to people three hours before the event happens. The performance categories could be:

- the degree of response;
- the effectiveness of action taken;
- the flood warning lead time.

3.4.6 Other communication

The measures of performance should differentiate between communication inside and outside the Environment Agency. Those who assess communication performances outside the Environment Agency should include communication with the Meteorological Office, the 'blue light' services, between responders, and to and/or from the public. The assessment of how data are communicated from these actors is also important.

3.4.7 Coordination

It is important to gauge and assess, through some form of measurement, the coordinated workings of the Bronze, Silver and Gold Commands, and all that this entails. Co-ordination 'up' and 'down' the communication 'chain of command' is important to FIM performance, including between the Environment Agency and Defra and the Office of the Deputy Prime Minister (ODPM), with professional partners at several levels, with Local Authorities and voluntary bodies (for example, the Women's Royal Voluntary Service (WRVS)). The difficulty will be to determine what constitutes 'good' and 'poor' coordination, and how to prescribe in quantitative or semi-quantitative terms how coordination is improved.

3.4.8 Media management

Media management is important. However, it is not easy to see how it is best described in measurable terms. The categories with which we should be concerned include national TV, local TV, national radio, local radio and any other electronic media. The printed, internet and other media are also important. The rationale of using 'favourable' to 'adverse' comments as the measure of success could be used, but this needs to be tested in some way.

3.4.9 Equipment provision

Equipment failure (or the lack of equipment) accounts for many poor performances of FIM. Measures are needed for inadequacies in detection equipment (for example, rainfall and flow gauges), data processing equipment and communication equipment. However, extraneous equipment is also important, as it may have faults many stages removed from the FIM action (for example, power equipment). The whole field of 'flood fighting' equipment is also important (for example, the use of demountables, sandbags) and its operational effectiveness is of concern to the Environment Agency. Measures to quantify this equipment provision need to be assessed and tested.

3.4.10 Other categories

It may be that the categories above are insufficient to define the performance fully, but it is understood that there is a need for simplicity rather than a long checklist. However, it is not entirely clear where the operation of 'active' flood infrastructure (aside from demountables) such as barriers and gates fit in. A separate element under the process entitled 'Operation of flood defence infrastructure' with descriptors such as 'Unsuccessful implementation' and 'Successful implementation', along with additional categories, such as the Health and Safety

record in flood incidents, may be required. The Health and Safety record in flood incidents is a subject that could be mentioned under a number of the process categories. It is a topic that is discussed in much of the Environment Agency flood literature. It is important, as the Environment Agency obviously should not put their staff's lives or, indeed, those of other actors at undue risk in an over-ambitious FIM process during a flood just to achieve one of the above targets.

3.4.11 A conceptual tool to evaluate and identify flood incident management performance

Ideally, what is required is a method to evaluate and identify the performance of the FIM at any stage including:

- Pre- or post-flood;
- During a flood (that is, in real-time).

Pre-flood incident evaluation would allow flood incident managers to assess the 'condition' or 'health' of their FIM system: :

- (i) to satisfy themselves that improvements are in place after an earlier evaluation that identified shortcomings;
- (ii) to identify shortcomings that still need attention.

Post-flood evaluation would take the form of a critical hindsight review of a flood event management system along the lines of the following questions:

- Did the system perform as anticipated and as intended?
- If not, why not? What were the shortcomings?
- Overall, how well did the system perform and was the performance satisfactory?

Real-time performance evaluation is a theoretical possibility that might be transformed into a reality in certain circumstances, but the more rapid-onset of the flood the more rapid such an evaluation would need to be, and in some cases it might not be possible at all because of time pressures. However, in the case of a flood event that evolves over a number of days or even a number of hours, a real-time performance evaluation method could be useful.

Experimental methods to evaluate the condition of flood warning systems were developed in the mid-1990s by the Flood Hazard Research Centre as part of the EC-funded EUROflood research project (Parker and Fordham 1996). It was envisaged that flood warning systems typically evolved from rudimentary through to advanced stages of development in Europe.

Figures 3.1 and 3.2 provide the basis for developing a 'criteria-development' matrix evaluation method for flood event management for England and Wales. To do this a number of developments need to be introduced:

- convert the scale on the horizontal axis from a three-criteria system (that is, 'poor', 'average' and 'especially good') to something like a seven-point scale to provide for more scope to differentiate performance;
- envisage the scale as a developmental one in which FIM can be characterised as moving from a rudimentary system to an advanced or even ideal one (for example, incorporating 'seamlessness' as an element or criterion on the vertical axis);
- re-examine the elements, which we might refer to as criteria, with user input into this selection process to give a refined and possibly extended list of elements or criteria (without generating too many);

- each cell in the matrix will need a minimum threshold value assigned to it where possible to enable measurement or categorisation to be performed with some degree of accuracy and reliability.

Critical in developing such a model will be the picture of how FIM systems evolve or might evolve over time, which is probably best done by assembling a group of practitioners from various groups to shape this understanding.

The development of a model for real-time performance evaluation could be a further improvement, but would need greater selectivity about indicators and a focus upon the availability of data for categorisation and measurement during a real-time flood incident. However, in essence the principles of the two models can be the similar. Careful trials and pilots of these evaluation methods will be an essential part of bringing them to a stage at which they can become operational.

An example of employing performance indicators in a recent flood incident is included in Appendix A of this report, which provides details of how performance indicators could be applied to the Carlisle flood of 2005.

3.4.12 Data availability

One of the issues in developing performance indicators is the availability of data. A report on post-flood event appraisal (Defra and Environment Agency 2003a) indicated that post-flood event data collection and analysis is heavily weighted toward technical interests and that post-event appraisals of emergency responses and long-term recovery are very much less common than appraisals of the weather and flooding experienced. There would appear to be no national consistency in methods of data collection or analysis with respect to the performance of the FIM system. The collection and processing of the data on previous flood incidents would create a historical record of the event and allow comparison with other flood incidents and the predicted performance of the FIM.

3.4.13 The Analytic Hierarchy Process

Introduction

AHP is a mathematical decision-making technique that allows consideration of both qualitative and quantitative aspects of decisions. It has the potential to be used as a screening tool for the FIM process. It enables complex decisions to be reduced to a series of one-on-one comparisons and then synthesises the results. The first stage of AHP is to break down the decision problem into a hierarchy of decision elements. *Figure 3.4* shows the standard form of the AHP hierarchy.

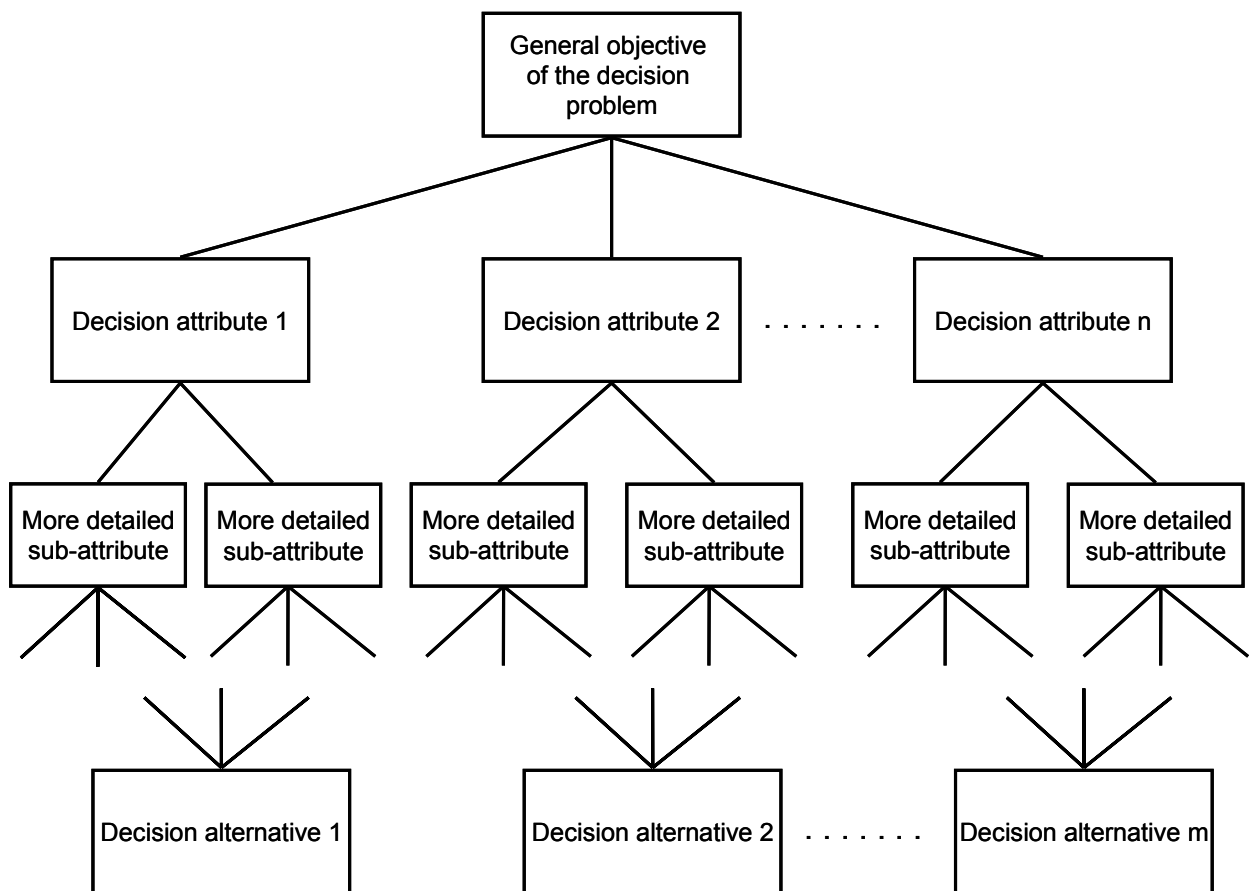


Figure 3.4 Generic Analytic Hierarchy Process hierarchy.

The objective is the top level, followed by the attributes considered important. Further dividing the attributes into sub-attributes creates the remaining levels and, finally, the alternatives are the bottom level. After the hierarchy has been established, weights must be assigned to each set of elements at the various levels.

AHP provides for both the analysis and synthesis of risk. It also combines both qualitative judgements and quantitative measures under a single umbrella. The bases of AHP are:

- construction of hierarchies of objectives and alternatives to meet those objectives;
- relative pairwise comparison of problem attributes including, where necessary, levels of uncertainty;
- a common scale to synthesise results;
- a sensitivity analysis capability.

One of the significant strengths of AHP is that it can measure the degree of inconsistency present in the pairwise judgements, and thereby help ensure that only justifiable rankings are used as the basis for decisions. AHP provides a good method for screening risks for the FIM process because:

- it provides a structured decision process;
- it is applicable to decision situations that involve multi-criteria;
- it can be applied to decision situations that involve subjective judgement;

- it uses both qualitative and quantitative data;
- it provides measures of consistency of preference;
- it is suitable for group decision-making.

The fundamental input to AHP is the decision maker's answers to a series of questions of the general form, 'How important is criterion A relative to criterion B?' These are termed pairwise comparisons. Questions of this type may be used to establish, within AHP, both weights for criteria and performance scores for options on the different criteria.

AHP is conducted in following the following steps:

1. set up the hierarchy (factors or options and alternatives);
2. perform pairwise comparisons for factors;
3. prepare a matrix (judgement matrix) for factors;
4. compute the priority vector for factors;
5. compare alternatives;
6. compute the priority vector for alternatives;
7. assess consistency of pairwise judgements;
8. compute the relative weights and/or ranks.

3.4.13.1 Example of risk screening using the Analytic Hierarchy Process

AHP is best illustrated by a simple example. Consider a floodplain that has five different options available to evacuate people from it:

- road,
- rail,
- boats,
- helicopters,
- walk.

The problem needs to be structured into a hierarchy. In this case the hierarchy is extremely simple as the goal is to establish which form of transport is most important in terms of evacuating people from the floodplain. The hierarchy is shown in *Figure 3.5*.

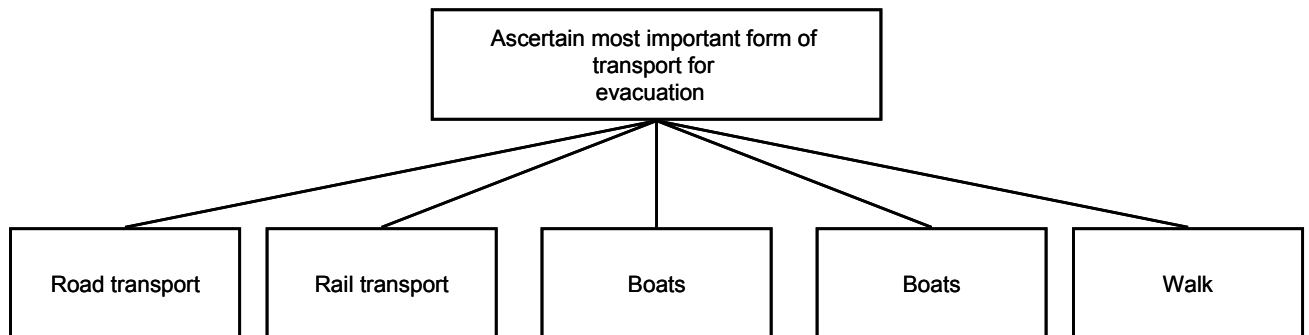


Figure 3.5 Hierarchy for ascertaining most important form of transport for evacuation.

The objective of the screening exercise is to determine where the most effort should be directed in terms of planning evacuation transport from the floodplain. AHP requires input from key groups with a good knowledge of the FIM process. In this example participants would include:

- Environment Agency staff;
- emergency planners from local authorities;
- representatives of the emergency services;
- representatives of the search-and-rescue community (for example, Royal Air Force, Royal National Lifeboat Institution).

AHP does not require groups to quantify precisely the level of importance of each option, but they are required to carry out pairwise comparisons among factors to give the relative importance of each pair according to the established nine-point intensity scale systems shown in *Table 3.3*. The factors are compared with each other to determine the relative importance of each factor in the accomplishing the overall goal.

Table 3.4 gives details of the fundamental scale. This is a scale of absolute numbers used to assign numerical values to judgements made by comparing two elements, with the smaller element used as the unit and the larger one assigned a value from this scale as a multiple of that unit.

A judgement or comparison is the numerical representation of a relationship between two elements that share a common parent (in this case transport method for evacuation). The set of all the judgements can be represented in a square matrix in which the set of elements is compared with itself. In this example, the various elements are road, rail, boat, helicopter and walk.

Each element is listed on the top row and left-hand column of the matrix. Each judgement represents the dominance of an element in the column on the left over an element in the row on the top. It reflects the answers to two questions:

- (i) Which of the two elements is more important with respect to a higher level criterion?
- (ii) How strongly the two elements are weighted is important with respect to a higher level criterion (for example, in this example where should the evacuation planning effort with respect to transport be prioritised).

Table 3.3 The fundamental scale used in the Analytic Hierarchy Process.

Comparative Importance	Definition	Explanation
1	Equally important	Two decision elements (road and rail) equally influence the objective
3	Moderately more important	One decision element is moderately more influential than the other
5	Strongly more important	One decision element has a stronger influence than the other
7	Very strongly more important	One decision element has significantly more influence over the other
9	Extremely more important	The difference between influences of the two decision elements is extremely significant
2, 4, 6, 8	Intermediate judgement values	Judgement values between equally, moderately, strongly, very strongly and extremely

Based on the informed judgement of informed stakeholders, the matrix is then filled in with numerical values that denote the importance of the factor on the left relative to the importance of the factor on the top. A high value means that the factor on the left is relatively more important than the factor at the top. If the element on the left is less important than that in the top row of the matrix a reciprocal value is entered in the corresponding position.

In *Table 3.4* for example, road is considered to be three times as important as rail, whereas boat is only one-third as important as the walk. When a factor is compared with itself the ratio of importance is obviously one, which results in a diagonal line across the matrix. The resulting matrix is known as the judgement matrix.

Table 3.4 Judgement matrix.

	Road	Rail	Boat	Helicopter	Walk
Road	1	3	4	2	2
Rail	1/3	1	2	2	2
Boat	1/4	1/2	1	1/3	1/3
Helicopter	1/2	1/2	3	1	1
Walk	1/2	1/2	3	1	1
Total	2.583	5.500	13.000	6.333	6.333

The next step is to calculate the overall priority value for each element. An overall priority value can be calculated in many ways. The simplest method is to calculate the 'priority

vector'. This is done by multiplying the values in each row and then taking the n th root, where n is the number of elements in the row. In this example these values are:

Road	$= (1 \times 3 \times 4 \times 2 \times 2)^{1/5}$	$= 2.17$
Rail	$= (1/3 \times 1 \times 2 \times 2 \times 2)^{1/5}$	$= 1.21$
Boat	$= (1/4 \times 1/2 \times 1 \times 1/3 \times 1/3)^{1/5}$	$= 0.42$
Helicopter	$= (1/4 \times 1/2 \times 1 \times 1/3 \times 1/3)^{1/5}$	$= 0.94$
Walk	$= (1/2 \times 1/2 \times 3 \times 1 \times 1)^{1/5}$	$= 0.94$
Total		$= 5.70$

The priority vector values are then calculated by normalising the values by the sum:

Road	$= 2.17/5.70$	$= 0.38$
Rail	$= 1.21/5.70$	$= 0.21$
Boat	$= 0.42/5.70$	$= 0.07$
Helicopter	$= 0.94/5.70$	$= 0.17$
Walk	$= 0.94/5.70$	$= 0.17$
Total		$= 1.00$

It is important to note that judgements in the matrix may not be consistent. In eliciting judgements redundant comparisons are made to improve the validity of the answer, given that the respondents may make poor judgements in comparing some of the elements. Redundancy gives rise to multiple comparisons of an element with other elements and hence to numerical inconsistencies. It is difficult to assess which judgements are more accurate and which cause inconsistency. Inconsistency is inherent in the judgement process. However, the inconsistency may be considered tolerable if it is a lower order of magnitude (10 per cent) than the actual measurement itself; otherwise, the inconsistency would bias the result by a sizeable margin compared to the actual measurement itself.

A consistency ratio (CR) is commonly used to reflect the degree of consistency in the judgement matrix. CR is calculated as follows:

$$CR = \frac{CI}{RCI}$$

where

CI is the consistency index
RCI is the random consistency index, given by:

$$CI = \frac{|\lambda_{\max} - n|}{(n - 1)}$$

where

λ_{\max} is the maximum eigenvalue value
 n is the number of pairs

Table 3.5 provides values for RCI. Further details of how the AHP method can be applied are provided in Annex 3.

Table 3.5 Random consistency index (RCI).

n	1	2	3	4	5	6	7	8	9
Random consistency index	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The maximum eigenvalue λ_{\max} is obtained by adding the columns in the judgement matrix and multiplying the resultant vector by the vector of priorities.

Road	= 2.58 × 0.38	= 0.98
Rail	= 5.50 × 0.21	= 1.15
Boat	= 13.0 × 0.07	= 0.91
Helicopter	= 6.33 × 0.17	= 1.07
Walk	= 6.33 × 0.17	= 1.07

Total λ_{\max} = 5.18

$$CI = \frac{|5.18 - 5|}{(5 - 1)} = 0.045$$

$$CR = \frac{0.045}{1.12} = 0.04 = 4.0\%$$

The pairwise comparisons in a judgement matrix in AHP are considered to be adequately consistent if its CR is less than 10 per cent. If CR is greater than 10 per cent, further evaluation of the pairwise comparison in the judgement matrix is needed. In the example above, CR is 4 per cent, which indicates that the pairwise comparison is consistent. In terms of prioritising an assessment of risk for evacuation transport, the different modes can be ranked:

1. Road (Relative weight = 0.38)
2. Rail (Relative weight = 0.21)
3. Helicopter (Relative weight = 0.17)
3. Walk (Relative weight = 0.17)
5. Boat (Relative weight = 0.07)

3.4.13.1.1 Conclusions

Pairwise comparisons are generally found to be readily accepted in practice as a way to establish information about the relative importance of criteria and the relative performance of options. AHP fits comfortably with circumstances in which judgements, rather than measurements of performance, are the predominant form of input information, which is often the case in FIM.

The example used to illustrate AHP is very simple. However, AHP can be used to help screen the risk for far more complex situations. Several pieces of commercially available software can be used to implement AHP.

Software is available with a structuring module that provides an interface mechanism to derive criteria and subcriteria. It has a framework to collect ideas and transform these into an AHP model, a facilitating mechanism to construct models. In a bottom-up approach, criteria are developed by listing the pros and cons of individual alternatives, grouping these into clusters and converting each cluster into a generic objective (criteria). The criteria are then organised into the hierarchy of the AHP model. Models can also be built using a top-down approach, in which objectives (criteria) are defined and then organised into the AHP hierarchy.

AHP has been widely used in air traffic management, which is a highly dynamic, complex domain. The evaluation of aviation risk typically involves a group of decision makers assessing trade-offs among competing attributes, such as safety, business concerns and risk that have many similarities with FIM.

The Federal Aviation Administration (FAA) in the USA has used AHP to identify efficiently the relative importance of aviation safety risk factors. This process allowed the FAA to gain an understanding of the rationale behind decisions made in situations that involved risk. This allowed the FAA to direct its relatively limited resources toward identifying the major risk-associated areas to prevent future incidents.

3.5 Tier 2 and 3 tools – Bayesian networks

3.5.1 Background to Bayesian networks

The research carried out in WP4 reviewed a number of different tools available to analyse complex systems, such as the FIM process. For more details of the various methods available, Annex 4 should be read in detail. The review in Annex 4 of the various methods available concluded that Bayesian networks are the most applicable and practical of the complex modelling systems in terms of use in the risk assessment of FIM.

A Bayesian network is a form of probabilistic graphical model. The network is a directed graph of nodes and arcs that represent variables and dependence relations among the variables, respectively. A node can represent any kind of variable, be it an observed measurement, a parameter, a latent variable or a hypothesis. In general, Bayesian networks describe situations in which elements in a situation can be causally connected, with conditional probabilities associated with the connections. They can be used to determine probabilities of particular states of events in the described situation, when some part of the situation has been observed.

Using a Bayesian network offers many advantages over other methods to determine causal relationships. Independence among variables is easy to recognise and isolate, while conditional relationships are clearly delimited by a directed graph edge – two variables are independent if all the paths between them are blocked. Not all the joint probabilities need to be calculated to make a decision; extraneous branches and relationships can be ignored

A method to estimate the probabilities of outputs of each system component depending on its inputs is required. The number should reflect the best information available. This can be done in several ways, for example:

- use information on the behaviour of the components, as assessed by scientific theory;
- use empirical information on past behaviour;
- use probability estimates given by experts;
- use probability estimates given by FIM practitioners.

To apply a Bayesian network approach to the part or all Environment Agency's FIM the following would need to be carried out:

- (i) assess the reliability of key FIM components (that is, detection, forecasting, warning and response to emergencies);
- (ii) understand the integration of the operation of key components within a FIM process during a flood;
- (iii) assess the improvement of the performance of the FIM process for various options;
- (iv) support risk assessment and decision-making tools related to flood and coastal erosion risk management at different decision levels within the Environment Agency.

3.5.1.1 Assess the reliability of key flood incident management components (that is, detection, forecasting, warning and response to emergencies)

This assessment requires the following to be defined:

- the element of the FIM process to be assessed;
- data on the reliability of components of the FIM system in terms of estimated probabilities, for example, using:
 - data on the operational failure of flood defence assets, such as failure rates (per year or on demand), failure modes and failure causes and consequences;
 - data on the probability and consequences of failure of reactive mitigation measures in relation to the supporting infrastructure (that is, assets other than flood defence assets) and personnel managing the flood events, including transport, utilities (for example, gas, water and electricity), communication networks, emergency services, health services.

3.5.1.2 Understand the integration of the operation of key components within a flood incident management process during a flood

To understand the integration of the operation of the key components requires:

- a definition of how all system components are interrelated;
- a simulation of the system behaviour using the definitions of the system components and their interrelationships, as well as data on the uncertainty and reliability of components' performance yet to be compiled.

3.5.1.3 Assess the improvement of the performance of the flood incident management process for various options

To assess the improvement of the performance requires:

- a definition of the options to improve the performance of the FIM system components;
- simulation of the system with the different options;
- assessment of the options using the developed performance indicators;
- evaluation of which option is the best in terms of overall system performance improvement.

3.5.2 Issues with Bayesian networks

There are two key issues with respect to the use of Bayesian networks. First, it is difficult to define comprehensively a complex process such as the FIM. To estimate the probability of any branch of the network, all branches must be calculated. This could be costly and time consuming to achieve. Hence, it is important that some form of risk screening is undertaken to enable a particular element of the FIM process to be analysed in detail.

The second issue centres on the quality and extent of the prior beliefs used in Bayesian inference processing. A Bayesian network is only as useful as this prior knowledge is reliable. For example, either an excessively optimistic or pessimistic expectation of the quality of these prior beliefs will distort the entire network and invalidate the results. Related to this concern is the selection of the statistical distribution induced in modelling the data. Selecting the appropriate distribution model to describe the data has a notable effect on the quality of the resulting network.

3.5.3 Application of Bayesian network to flood incident management

The application of a Bayesian network can be used to assess the probability of 'failure' of the FIM process. The village of Pill is located to the south of Bristol. It is protected from tidal flooding by a flood defence scheme, together with a number of tidal sluice gates that are manually operated. In the year 2000 particularly high tides were forecast and, as a result, operational teams were dispatched to shut the gates. Owing to the exceptional traffic conditions the team did not reach the gates in time to shut them and a number of properties were flooded. The FIM process for Pill is shown in the form of a simple Bayesian network in *Figure 3.6*.

This approach could have been used as a basis for a risk assessment process in the case of Pill to analyse the 'weak links' in the process. Probability distributions for the various links in the network could have been ascribed from various sources, including:

- the detailed method included in the Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) will, in the future yield, the probability of failure of flood defence infrastructure, as well as details of the physical conditions at a site;
- probability distributions for the other links would have been elicited from expert judgements.

One key advantage of Bayesian networks is the ability to form inferences about, in this case, the FIM process for Pill when the input information is incomplete or uncertain. The analysis can be refined as more data become available, and as flood incident managers are able to devote more attention to updating information regarding their actions and observations.

In the case of Pill one of the solutions that a Bayesian network could have been used to investigate was the effect of some redundancy into the system. This could have been the introduction of other bodies (for example, the police, other Environment Agency staff) with the correct equipment and training located near the site who could shut the gate if the Environment Agency operational team did not arrive in time. This scenario could have been analysed using a Bayesian network and assessed as to whether it was a 'good solution' in terms of the performance indicators outlined in Chapter 3 of this report.

3.5.4 Conclusions

There are many advantages to the use of Bayesian networks to reduce risk in the FIM process. Decisions on improvements and changes to this process, its procedures and its associated infrastructure should be determined on the basis of many of the factors detailed in the performance indicators in Chapter 3 of this report. It appears that traditional decision-making processes do not provide repeatable, auditable or quantitative arguments, and rely heavily on the knowledge and experience of key FIM staff. This knowledge and experience may be lost to future assessors when staff retire or leave the Environment Agency.

A Bayesian network approach could be used to model the critical parts of the FIM process and make important predictions on how to minimise risk in this process. Using this approach it could be estimated how the probability and consequences of 'failures' in the FIM process could be modified in different ways.

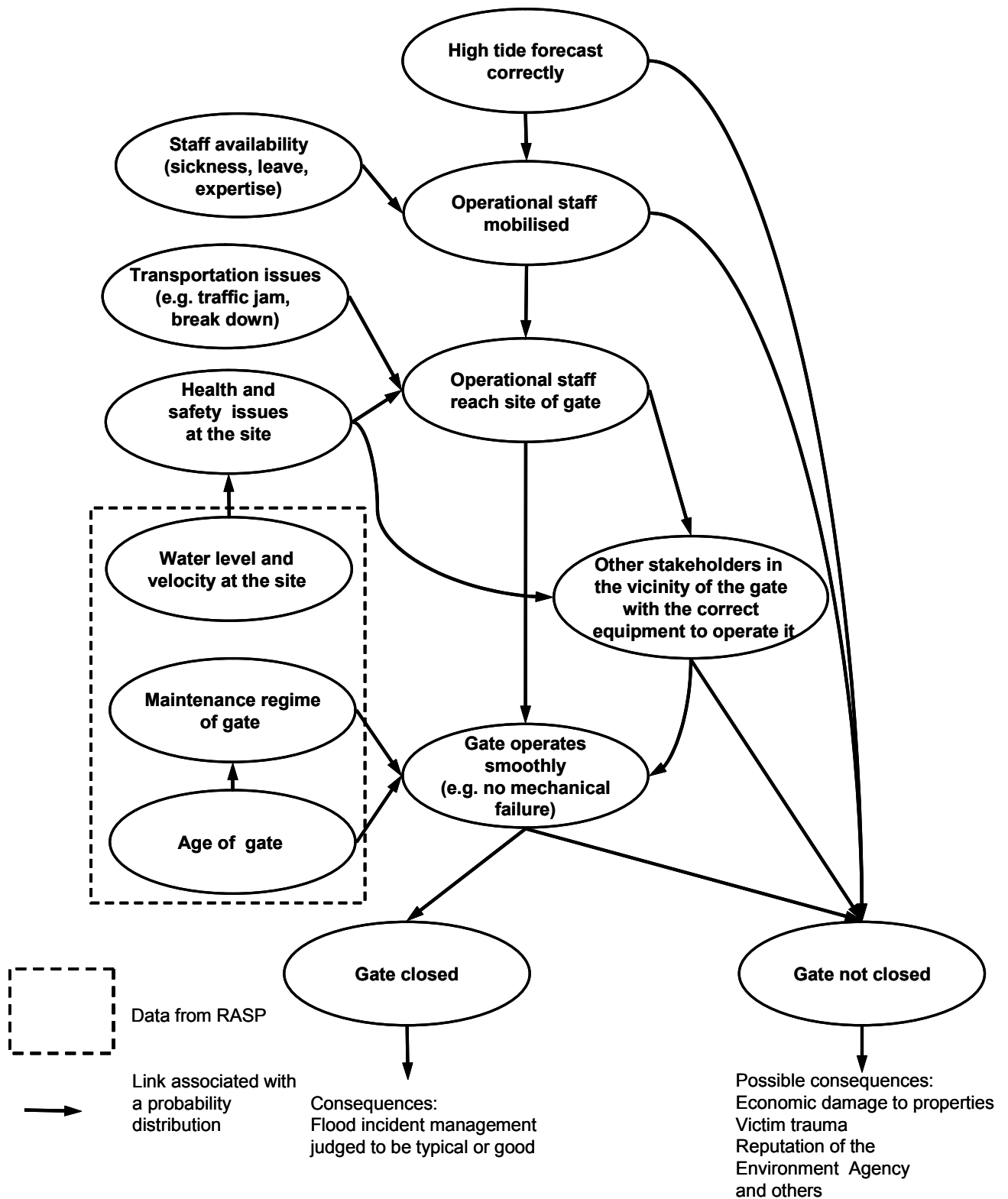


Figure 3.6 Representation of the flood incident management process for a site at Pill near Bristol.

4 Conclusions and recommendations

4.1 Conclusions

The following general conclusions can be made concerning FIM in England and Wales:

- little research has been carried out on both the effectiveness and risk assessment for FIM, both in the UK and overseas;
- quantitative data available on the FIM process are limited and tend to be focused on more 'technical' parts of the process, such as flood forecasting;
- performance of the FIM process is rarely measured and a 'failure' of it is not well defined;
- there is a requirement to develop performance indicators for the FIM process so that 'failures' and 'underperformance' can be quantified in terms of their effect on the process and the outcomes;
- consequences that occur because of the 'failure' or 'underperformance' of the FIM process are rarely quantified;
- there is little Government guidance on what constitutes 'good incident management' (other than to minimise loss of life);
- the FIM process is a complex system, in that:
 - relationships can be non-linear;
 - relationships contain feedback loops;
 - the process is not self-contained;
 - the process will change of the course of time and its prior state can influence its present state;
 - it is nested;
 - the boundaries are difficult to determine;
- There is a need for a tiered risk assessment process, similar to that employed by the Environment Agency in flood risk management;
- As the FIM process is a complex system there is a need for a risk screening tool to assist flood incident managers, practitioners and planners to focus their efforts on the 'weakest links' in it.

4.2 Recommendations

The key recommendations are given below.

4.2.1 Development of flood incident management performance indicators

It is recommended that the preferable approach is to consider and evaluate FIM systems using some kind of performance scale that, crudely –speaking, ranges from poor to good. In Phase 2 it is proposed that three types of performance indicators for pre-flood, post-flood and real-time performance evaluation should be considered. These should be constructed with user inputs at the design and subsequent piloting stages.

The 'performance' of a FIM system is not an entirely objective matter. Performance of public sector services may be measured using technical measures of delivery, but they are also assessed and judged qualitatively by the groups involved with those services. This leads to impressions and perceptions of such services that are at least as important, if not more important, in the final analysis to determine how services are considered to have performed. It is therefore recommended that to manage the expectations of different groups is a critical element of FIM, such that it really consists of two elements:

- management of the flood event – processes and outcomes;
- management of the flood event management groups.

There is a requirement to develop performance indicators with the key members of the FIM process team. Chapter 3 of this report provides a possible starting point for this. However, there is still a need to consult with the key actors in the FIM process to establish:

- What performance indicators are going to measure.
- How the information is provided by the performance indicators.
- The number of performance indicators required. For example, are a smaller number of performance indicators going to be more effective than a large number?

It is important that any performance indicators developed are effective and provide a balanced picture of the FIM process.

4.2.2 Development of a three-tier risk assessment framework for flood incident management

It is recommended that a three tiered approach to risk assessment in FIM is adopted. This would allow proportionate effort to be applied, based on a number of factors, including:

- decision-making requirements;
- scale of the risk;
- degree of uncertainty;
- size of the catchment;
- unique characteristics of the catchment.

This tiered approach needs to be tested in close collaboration with a number of different actors in the FIM process. As FIM is a complex system, a risk screening process is needed so that the 'weak links' in the process can be identified and investigated in more detail.

4.2.3 Development of performance indicators and AHP as screening tools in the risk assessment process

The use of performance indicators and AHP needs to be further developed and assessed as a screening tool that uses data collected from recent 'failures' in the FIM process.

4.2.4 Use of Bayesian networks to analyse the flood incident management process at catchment and sub-catchment levels and below

The use of Bayesian networks needs to be further investigated for various components of the FIM process. A number of pieces of software are commercially available. The practicalities of using Bayesian networks need to be further investigated using data collected from recent flood incidents.

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Appendix A

The Carlisle flood incident January 2005 case study: an example of flood incident management performance and its assessment

Aims of this case example task

The Carlisle flood in January 2005 has been analysed in detail. It is not the intention, here, to give all the details and repeat that analysis because this will not add to the Environment Agency's current knowledge of the incident and the performance of the flood incident management (FIM) effort there. The objective is to determine the extent that the framework encapsulated in *Figures 3.1* and *3.2* would be useful in assessing the success or otherwise of FIM.

Background to the flood incident management

The key performance characteristics of the FIM in Carlisle, detailed in the debrief report published by the Government Office for the North West *et al.* (2005), were:

1. A failure of power supply.
2. Subsequent failure of the telecommunications system (a major cable failed).
3. Failure of the mobile telephone networks caused by power supply failure.
4. Hence, there was no 999 telephone service in North Carlisle.
5. No 'Plan B' for failures induced by power outages.
6. Less than 50 per cent of the at-risk population were served by the automated voice messaging (AVM) system.
7. There were some differences in culture within the Gold Command system.
8. Too many alerts had, perhaps, been issued in the past, which lead to response degradation.
9. Some 'new responders' (who had not been involved before in flood events and were now involved, thanks to the Civil Contingencies Act) were not well engaged with response systems and procedures.
10. The capacity of 'new responders' to assist in the flood event management was not fully appreciated or fully utilised.
11. The Civic Centre was flooded, and therefore lost as a communication 'hub'.
12. Communications between Gold and Silver Commands 'were not good'.
13. The lack of a common radio system hindered communication.
14. There was a lack of good maps of the affected area outside the Silver Command system.
15. There was a lack of records of those who were rescued or evacuated.
16. There was no system responsible for ordering and organising transport.
17. There was no plan to manage the designation of reception centres.
18. There was no plan to manage voluntary contributions to the flood event management.
19. There was a lack of a media liaison presence in Silver Command.
20. Responder organisations did not plan the use of their staff well enough.
21. Previous training exercises organised by the local authorities had suffered through lack of up-take.

In summary, the problems at Carlisle categorised in the debrief report (Government Office for the North West *et al.* 2005) were:

1. Pre-incident warnings.
2. Communications.
3. Response coordination.
4. Provision of information to the public.
5. Business continuity (planning).
6. Planning and training.

However, this list is balanced by the contention in the report that 'many of the recommendations (for the enhancement of FIM) suggest that the existing systems are enhanced, rather than there being key gaps in provision' (Government Office for the North West *et al.*, 2005).

Figures A.1 and A.2 attempt to apply the multi-criteria performance assessment tool developed in Section 3.4 to this situation. As such this tool, in fact, contributes very little to the *analysis* of the incident as managed, but does perhaps provide a good *summary* of the situation. If each element had been scored on a scale of 1 to 10, then the score for this event would have averaged '3' or '4', as against a set national all-time current average of '5'. Most of the 'poor' scores would have been awarded for the loss of life in Carlisle and the communication difficulties, facts that were well known and did not, in fact, require further analysis.

Conclusions of the case study

The analysis of FIM performance in a real event is always revealing, be it the floods in 1947, 1953, 2000 or in Carlisle in January 2005. FIM in Carlisle, which involved two deaths and severe communication problems, was not as good as it should have been.

The main problems that remain appear to be communication, coordination, skills and training. However, it does not take this FIM report to tell the Environment Agency this; the matter is well-enough dealt with in the debrief report. Even Figures A.1 and A.2 add rather little to the insights that are needed for better incident management: we just need better communication, coordination, skills and training! However, it does allow shortcomings in the FIM system not only to be identified, but also to be ranked. This enables the areas of most concern to be concentrated on.

		Flood incident management (FIM) descriptors and/or numbers			
		“Particularly poor” FIM	“Typical” or “average” FIM today	“Especially good” FIM	Elaboration and categorisation
Process	Preparedness	Poor state of preparedness	Good preparedness levels	Excellent state of preparedness	Categories: Awareness raising; training; pilot exercises; appropriate documentation, contingency plans
	Forecasting	Flood forecast very poorly in terms of accuracy	Some forecasting accuracy problems	Floods forecast accurately in terms of time and extent	Categories: Detection; forecasting; warning messages; dissemination; response; review
	Warning and Promoting response	<50% of warnings received in time for sensible response	75% of warnings received in time for sensible response	95% of warnings received in time for sensible response	Categories: Warning messages; dissemination; response; review
	Other communication	Major communication problems	Some communication problems	No major communication problems	Categories: Inside Agency; outside the Agency; Met Office; between responders; to/from public; from gauges; to sirens
	Co-ordination	Distinct lack of co-ordination	Good co-ordination	Immaculate co-ordination no problems at all	Categories: Bronze; Silver and Gold command; DEFRA/ODPM; professional partners; voluntary bodies
	Media management	Media poorly managed	Good media management	No major media management problems	Categories: National TV; local TV; national radio; local radio; printed press locally; printed press nationally; internet; others
	Equipment provision	Clear equipment shortcomings	Some equipment lacking	All relevant equipment available and in place	Categories: Detection (gauges etc); data processing; communication; power; ‘flood fighting’ (dountables) other equipment

Figure A.1 An assessment of the flood incident management process in Carlisle in 2005 using the performance assessment framework.

		Flood incident management (FIM) descriptors and/or numbers			
		“Particularly poor” FIM	“Typical” or “average” FIM today	“Especially good” FIM	Elaboration and categorisation
Outcomes	Environmental damage	Unwarranted environmental damage	Minor environmental damage	Negligible environmental damage	Categories: Flora; fauna; landscape; archaeological remains; others
	Economic damage	Unwarranted property damage	Less than Multi Coloured Manual damage	Much less than Multi Coloured Manual damage	Categories: Residential; non-residential; public buildings; infrastructure damage (utilities); others
	Injuries	Greater than 5	Equal to or greater than one	0	Categories: Immediate and directly flood related; medium term effects (direct and indirect)
	Loss of life	Equal to or greater than one	0	0	Categories: Age; gender; social class; local/visitor; prior health status
	Victim trauma etc	Greater than 25 people affected	Equal to or greater than five people	No people affected	Categories: Age; gender; social class; local/visitor; prior health status
	Reputation of Environment Agency and others	More negative than Positive comments	Less than 33% negative comments	Less than 20% negative comments	Categories: Public nationally; public locally; politically (MPs; DEFRA; ODPM) with professional partners

Figure A.2 An assessment of the flood incident management outcomes in Carlisle in 2005 using the performance assessment framework.

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