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source

pathway

receptor

Framework and tools for local flood risk assessment: project report

SC070059/R3

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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.

This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal Erosion Risk Management Research and Development Programme.

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

This report was produced by the Research, Monitoring and Innovation team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;

- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;

- **Carrying out 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.

Miranda Kavanagh

Director of Evidence

Executive summary

The flooding incidents of summer 2007 provided an extreme example of the cost and misery that surface water flooding causes, but on a local scale such flooding can and does happen frequently. Our drainage systems have not always been designed on a strategic basis and many have grown in a piecemeal manner in response to development. Not all can cope now and with the *UK Foresight Future Flooding* report stating that flood risk in urban areas could increase two- to twenty-fold over the next 100 years, the impacts will get worse. While there is an established process for assessing and managing flooding risks from rivers and the sea, local flood risk is potentially much more complex and organisation responsibilities and management processes have, until recently, been less well defined.

New roles and statutory responsibilities for flood risk management in England and Wales are set out in the Flood and Water Management Act 2010 and Flood Risk Regulations 2009. Lead local flood authorities (LLFAs) now lead on local flood risk (flooding from surface runoff, groundwater and ordinary watercourses). The Environment Agency has a strategic overview of all sources of flooding in England and a similar strategic oversight role in Wales. A key part of this role is providing guidance and tools to LLFAs to help them meet their new responsibilities.

The assessment of risk is the first stage in the planning and management of flooding.

Risk assessment approaches are well established for rivers and the sea (the Environment Agency's hierarchy of Risk Assessment for System Planning methods used in the national flood risk assessment) and are emerging for local flood risk through the Department for Environment, Food and Rural Affair's (Defra) *Surface Water Management Plan Technical Guidance* and the sources referenced therein. It is therefore important that this project produces tools and information that is useable and consistent with the local flood risk management strategy, Flood Risk Regulations and Surface Water Management Plan processes, development frameworks and technical guidance.

The methods and software tools described in this report have been developed to meet a number of basic requirements that emerged from consultation with LLFA-led flood risk management partnerships. According to these users, the project's outcomes should:

- **Be simple to understand and efficient to apply**. LLFAs have limited resources for investigating and alleviating local flood risk issues that should not be absorbed by esoteric or onerous risk assessment tools. These should be reproducible (if required) by all local partners.

- **Be implemented by LLFAs** to ensure the desired transparency in the source and quality of input data, and establish confidence in the final risk assessment outputs.

- **Use the best available information wherever possible**. This could be "default" flood risk datasets, such as the Environment Agency's fluvial and coastal Flood Map, surface water flood maps and National Receptor Dataset, or LLFAs' own hydraulic models and receptor data held locally. LLFAs have determined "locally agreed surface water information" as part of the Preliminary Flood Risk Assessments (PFRA) process, which sets out the national and local surface water datasets that best represent local conditions. The project's outcomes should therefore be compatible with widely available datasets, modelling approaches and software.

- **Be highly visual and GIS-based**. The methods and software tools should help to communicate flood risk to non-technical decision-makers, partners and interested/affected groups. They should also be able to provide spatial summaries that are easy to share with, and be interpreted by, local authority colleagues (for example, for emergency and spatial planning purposes).

- **Be independent of spatial scale and flood probability/scenario**. Users must be able to apply the same methods regardless of the size of the study area, the spatial detail required and the range of flood probabilities/ scenarios under consideration.

- **Be able to investigate the impacts of changes to the physical system** (such as climate change, urban creep, new development, introduction of flood risk management measures). The outputs from the risk assessment should support options appraisal and provide quantitative evidence to inform investment decisions (such as Flood Defence Grant-in-Aid applications).

- **Add to the evidence base to support balanced local decision-making**. The framework, methods and prototype software tools developed must appreciate the importance of balancing the economic, social and environmental consequences of flooding for local authorities as democratically-elected organisations.

- **Help LLFAs to meet their legislative requirements**.

This project has set out to meet these requirements by generating a **final project report** (this document) that describes methods for local flood risk assessment presented in terms of the level of knowledge, models and data required for their use. Accordingly, the methods have been split into those that can be adopted by: **any user** with access to national flood risk datasets provided by the Environment Agency; **some users** with locally-available hydraulic models and data; and the **few users** with potentially complex hydraulic models, advanced risk assessment tools and research capability. These methods are incorporated into the prototype software tools and are demonstrated for two example applications, broad-scale screening of flood consequences and a detailed risk calculation to support benefit-cost analysis of potential flood mitigation options, for two pilot LLFAs.

The **prototype software tools** demonstrate the functional implementation of the risk assessment methods. These tools are not intended to be business-ready software applications, which would require more precise specification of how they will be used and by whom. However, the prototype tools developed here are usable by third parties for evaluation and demonstration purposes, provided they meet certain operating system and software dependency criteria and comply with the relevant licensing arrangements.

The **prototype software tools** are able to calculate and view the number of people or properties affected by any flood scenario in any chosen area. **"Quick start" supporting guidance** for the prototype software tools can be found in the accompanying document, *SC070059 - Framework & Tools for LFRA - Software User Guide - Final.pdf*.

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Contents

1   Introduction

1.1   Project overview

This project, *Framework and Tools for Local Flood Risk Assessment* falls under the Modelling and Risk Theme within the Department for Environment, Food and Rural Affairs (Defra) and Environment Agency Joint Flood and Coastal Erosion Risk Management (FCERM) research and development programme. The project was originally called *Developing the Next Generation of Surface Water Flood Risk Assessment* but was changed to the current title in November 2010 to better reflect changes in the project scope and emphasis (see Section 1.2). These changes were approved by the Project Board and are set out in detail in a previous project report (SC070059/SR2).

The project is split into three phases. At the end of Phase 2, the Project Board shifted the focus from "surface water" to "local flood risk". This change recognised the Flood and Water Management Act 2010 definition of local flood risk (surface runoff, groundwater and ordinary watercourses) and the holistic definition of surface water used in the *Surface Water Management Plan (SWMP) Technical Guidance* (which includes local flood risk). The decision also aligns with the local-national division of responsibilities for different forms of flooding set out in the Flood Risk Regulations 2009 and the Flood and Water Management Act 2010.

This report is the main outcome from Phase 3. A full list of outcomes for this final phase of the project is provided in Section 1.3.

1.1.1   Aims and outcomes

This project aimed to create a framework, methods, and prototype software tools to help local authorities better understand and manage flood risk in their area. The prototype software tools were specifically included to demonstrate the "proof of concept" of the framework, for further operational development by the industry and partners. The work recognises new statutory responsibilities for flood and coastal erosion risk management in England and Wales and supports consistent risk assessment across multiple spatial scales as part of Surface Water Management Plans and local flood risk management strategy and Flood Risk Regulations-related studies. The framework responds to the need to adopt a risk-based approach in the assessment and management of flood risk.

The project outcomes are intended to:

- be widely accessible (easy to follow and compatible with widely available datasets, modelling approaches and software);

- be useable and consistent with the local flood risk management strategy, Flood Risk Regulations and Surface Water Management Plan processes, development frameworks and technical guidance;

- be conceptually consistent with the Environment Agency's hierarchy of Risk Assessment for System Planning (RASP) methods;

- assist partnership working in line with the Flood and Water Management Act (FWMA) and other responsibilities in spatial and emergency planning;

- support an open, flexible approach to flood risk assessment that is compatible with the different models, data and knowledge held by local flood and coastal erosion risk management (FCERM) partners;

- support better understanding and consistent communication of local flood risk through use of the best available models, data and local knowledge.

1.1.2   Phase 1: Scoping (October 2009 – February 2010)

The first phase of the project involved a detailed consultation exercise to develop a clear understanding of the needs of potential users for information on surface water flood risk and the methods available for providing that information. The consultation was supported by a desktop review of

- flood and coastal erosion risk management policy and strategy;

- methods, models and data for surface water flood risk assessments;

- technical guidance on assessing and designing measures for surface water flood risk.

The consultation findings and review material were presented in the Phase 1 Scoping Report (SC070059/SR1) and provided an important focus for Phase 2 of the project.

1.1.3   Phase 2: Method development (March 2010 – November 2010)

The risk assessment framework and methods were developed during the second phase of the project and are presented in the Interim Methodology Report (SC070059/SR2). They are designed to be readily accessible, efficient to run and meet local authority needs now and in the foreseeable future. They are also compatible, at a conceptual level at least, with the Environment Agency's hierarchy of RASP methods for fluvial and coastal flooding.

1.1.4   Phase 3: Further development, testing and delivery (December 2010 – July 2011)

During Phase 3, testing in pilot areas was carried out to finalise the framework, methods and prototype software tools and develop accompanying "quick start" guidance for local authority users.

Work was also done to identify how the project outputs, if "rolled out", could deliver wide-ranging benefits in local flood risk management. Options and issues for any subsequent operational deployment are also discussed.

1.2   Evolution of project scope

The original project specification sought to develop the "next generation" of risk assessment methods for surface water flooding. This was interpreted as a requirement to develop probabilistic risk modelling tools aligned, and capable of integration, with the Environment Agency's RASP methods for fluvial and coastal flood risk systems. As well as developing practical software tools, the project was also tasked with addressing

technical questions, the answers to which could be integrated within a "comprehensive, long-term scientific approach to assessing surface water flood risk at different spatial scales". Such questions included how best to:

- extend the Department of Trade and Industry (DTI) SAM-type probabilistic analysis of drainage system performance to consider additional flood sources (such as ordinary watercourses) and/or above-ground pathways;

- represent complex interactions between sources (boundary conditions) and pathways (above and below-ground hydraulic systems) in urban environments;

- manage potentially conflicting risk information at different spatial scales and levels of detail.

However, following the Phase 1 consultation exercise, guidance from the Project Board and changes to legislation and policy, the scope and requirements of the project evolved from those originally specified in the tender documentation. This process resulted in shifts in emphasis which are described below.

1.2.1   Greater focus on use by lead local flood authorities

The change in emphasis reflects the new statutory responsibilities of lead local flood authorities (LLFAs) for managing local flood risk (flooding from surface runoff, groundwater and ordinary watercourses) as recently formalised in the Flood Risk Regulations 2009 and the Flood and Water Management Act 2010 (FWMA) [see Sections 2.2 and 2.3]. While the Flood Risk Regulations only require flood hazard maps, flood risk maps and management plans to be produced for "flood risk areas" identified in Preliminary Flood Risk Assessments (PFRA), the FWMA states a duty on LLFAs to develop, maintain, apply and monitor a strategy for managing local flood risk across their administrative areas.

The FWMA also places a similar responsibility on the Environment Agency to develop a national strategy for FCERM in England and this was published in 2011. The Environment Agency has a strategic oversight role in Wales which will mean monitoring and reporting on the implementation of the national FCERM strategy for Wales developed by Welsh Assembly Government. These responsibilities include providing guidance to local and risk management authorities on the assessment and management of all flood risk. Therefore, methods developed must be compatible, at a conceptual level at least, with established risk assessment approaches for fluvial and coastal flooding.

1.2.2   Compatibility with RASP principles at a conceptual, rather than software, level

The focus on accessibility for LLFAs has meant there is no need to link methods with the Environment Agency's Modelling and Decision Support Framework 2 (MDSF2) software, which implements the RASP methods for fluvial and coastal flood risk systems at a local level. Also, while the RASP principles are fundamentally generic, they have specific interpretations within the MDSF2 software tools for fluvial and coastal flooding. As such, RASP and MDSF2 are currently not designed for assessing the sources and pathways of local flood risk. However, this project will identify opportunities to re-use or extend the functionality of MDSF2 where possible (such as use of common consequence and damage calculators).

1.2.3   Need for flexibility in applying source – pathway – receptor concepts to local flood risk

The source – pathway – receptor (SPR) concept is familiar through its adoption in RASP for fluvial and coastal systems (Defra/Environment Agency, 2006). It also provides a useful basis for considering the assessment and management of local flood risk, although it may be more difficult to apply in practice. Here, the SPR terms are defined in the context of local flood risk.

Sources are the physical conditions or load on the system (such as rainfall, river and coastal water levels) that create the risk. Usually they are the inputs or boundary conditions in system simulation models.

Pathways provide the routes for flood water to pass to receptors and are divided here into three key groups:

- above-ground/major system (surface topography, watercourses and drainage channels);

- below-ground/minor system (sewer networks and highway drains);

- "interface" assets that control transfers of flow between the two systems.

For local flood risk, a formal distinction between a source and a pathway is not always clear, and will depend on the level of detail considered and purpose of each application. For example, runoff from an urban subcatchment calculated using a lumped catchment rainfall-runoff model is considered as a source, which encompasses the minor hydraulic pathways such as highway drainage. However, the same runoff can be considered as a pathway where it is calculated using a direct rainfall, 2D modelling approach connecting to a detailed 1D model of highway drains and sewers. This reflects the complex nature of local flood risk, especially in urban areas.

Receptors are the properties, people, infrastructure assets and environmentally or culturally significant sites in the floodplain which are at risk of flooding. Part of the risk is related to the consequences receptors suffer (see Section 3.1). The consequences of flooding are the economic, social, environmental or cultural impacts that may result from a flood. Consequences can be expressed in monetary terms or using other metrics such as counts, lengths or areas of features affected by flooding.

In reality there are often multiple sources, pathways and receptors of local flood risk in any one area. Therefore, a method for estimating risk should ideally be able to integrate the various sources, pathways and receptors. This can add significant complexity when the pathways interact, for example, if the performance of a below-ground drainage system depends on the above-ground system or the state of intervening assets (such as highway drainage grilles). A related problem is which sources, pathways and flood mechanisms should be considered, and in what level of detail (see Section 3 for a full discussion).

We do not wish to exclude any source, pathway or flood mechanism from the risk assessment process. Provided all potential sources and mechanisms of flooding are represented within deterministic simulation models, their combined effects can be reflected in the subsequent risk and consequence analyses. Therefore, decisions on the inclusion of particular flood sources, mechanisms and mitigation measures (such as flood defence structures or sustainable drainage systems) can be tailored according to local user requirements.

1.2.4 Need for pragmatism and efficiency in implementation

The need for pragmatism and efficiency was stressed by all consultees and the emphasis, combined with the LLFA end-user focus outlined above, steered the project away from developing or extending detailed probabilistic, systems-based methods for local sources of flooding (methods analogous to RASP High Level Method Plus (HLM+)). Such techniques are emerging from recent research projects such as DTI SAM (HR Wallingford, 2009) but these are in their infancy and do not yet resolve multiple sources and/or above-ground pathways in sufficient detail to understand potentially complex "real world" local flood risk problems. Their uptake will also be limited in practice due to considerable data and computational overheads.

Instead, the methods developed here seek to maximise use of existing flood risk datasets, provided to LLFAs by the Environment Agency, and the models and data developed locally through partnership arrangements to support local flood risk management activities. Therefore, given the resources of the project and the findings of the Phase 1 consultation, we have focussed on risk assessment methods that are more readily accessible and meet users' needs now and in the foreseeable future. These are based on a conceptual platform that is compatible with the approach taken in assessments performed in recent years and appropriate for continued use in future cycles when implementing the Flood Risk Regulations (every six years).

1.2.5 Support local decision-making

Government's Localism agenda, supported by the Localism Bill, is giving local authorities more autonomy and accountability in their provision of services. Decision-making on planning issues will be a key area, with authorities working with the public, partners and neighbouring authorities on environmental issues (like flooding) and infrastructure. The Bill's duty to cooperate will require local authorities and other public bodies to work together on planning issues. This legislation exists alongside specific requirements in the Flood and Water Management Act for LLFAs to cooperate with other risk management authorities and act in a manner consistent with local and national strategies and guidance.

It is vitally important that the framework, methods and prototype software described here support local decision-making by allowing local flexibility and innovation in terms of how the flood risk is assessed whilst preserving a common conceptual approach. This flexibility should help to increase uptake among LLFAs. In addition, the common conceptual approach will facilitate discussion and support joint working between neighbouring authorities on flood risk issues.

1.2.6 Pilot testing to focus on LLFA-orientated risk assessment activities

LLFAs have limited resources for investigating and alleviating flooding issues that should not be absorbed by onerous and/or esoteric risk assessment approaches. Pilot testing should therefore focus on demonstrating the usefulness and usability of project outputs for risk assessment activities as part of Surface Water Management Plans and local flood risk management strategy and Flood Risk Regulations-related studies.

1.3 Final outcomes

The outcomes for Phase 3 consist of:

- **Final project report**. This document sets out the risk assessment framework and methods, and demonstrates their application using the prototype software tools for two pilot LLFAs. The report also describes how the project outputs could deliver wide-ranging benefits in local flood risk management if implemented across England and Wales.

- **Prototype software tools**. The project specification calls for the development of prototype software tools that demonstrate the functional implementation of the proposed risk assessment methods. These "proof of concepts" are not intended to be business-ready software applications, which would require more precise specification of how they will be used and by whom. However, the prototype tools described here are usable by third parties for evaluation and demonstration purposes provided they meet certain operating system and software dependency criteria (see Section 5) and comply with the relevant licensing arrangements.

  There are two prototype software tools. A calculator tool that calculates the flood risk, for example the number of people or properties affected by any flood scenario in any chosen area; and a viewer tool that allows users to view the distribution of flood risk, for example economic damages in any chosen area.

- **"Quick start" supporting guidance** for prototype software tools (*SC070059 - Framework & Tools for LFRA - Software User Guide - Final.pdf*).

1.4   Report structure

This report is set out as follows:

Section 1   Restates the aims and outcomes of the project. It also describes how the specification evolved over the course of the project to better meet LLFA requirements.

Section 2   Highlights the potential value of the project for supporting Surface Water Management Plans and local flood risk management strategy and Flood Risk Regulations-related studies.

Section 3   Sets out a simple, practical framework for local flood risk assessment.

Section 4   Introduces a suite of generic methods for local flood risk assessment that recognise the different levels of technical capacity and availability of local models and data across LLFAs.

Section 5   Describes the functional implementation of the generic risk assessment methods set out in Section 4 as prototype software tools.

Section 6   Applies the methods and prototype software tools developed in Sections 4 and 5 to data from Torbay and Gloucestershire LLFAs for two hypothetical cases.

Section 7   Outlines the wide range of potential users within the FCERM community that could benefit from the developments set out here.

Section 8   Discusses the main issues and options for future implementation of these tools and highlights further research requirements for local flood risk assessment.

2 Supporting local flood risk management

2.1 Overview

Successive governments have developed a range of policy and strategy responses to the issues and pressures affecting communities at risk from flooding. These were thoroughly reviewed as part of the Phase 1 Scoping Study and only the key points and more recent updates are summarised in Sections 2.2-2.4 below. To help understand the links between different plans, strategies and frameworks, a local flood risk management organogram is shown in Figure 2.1.
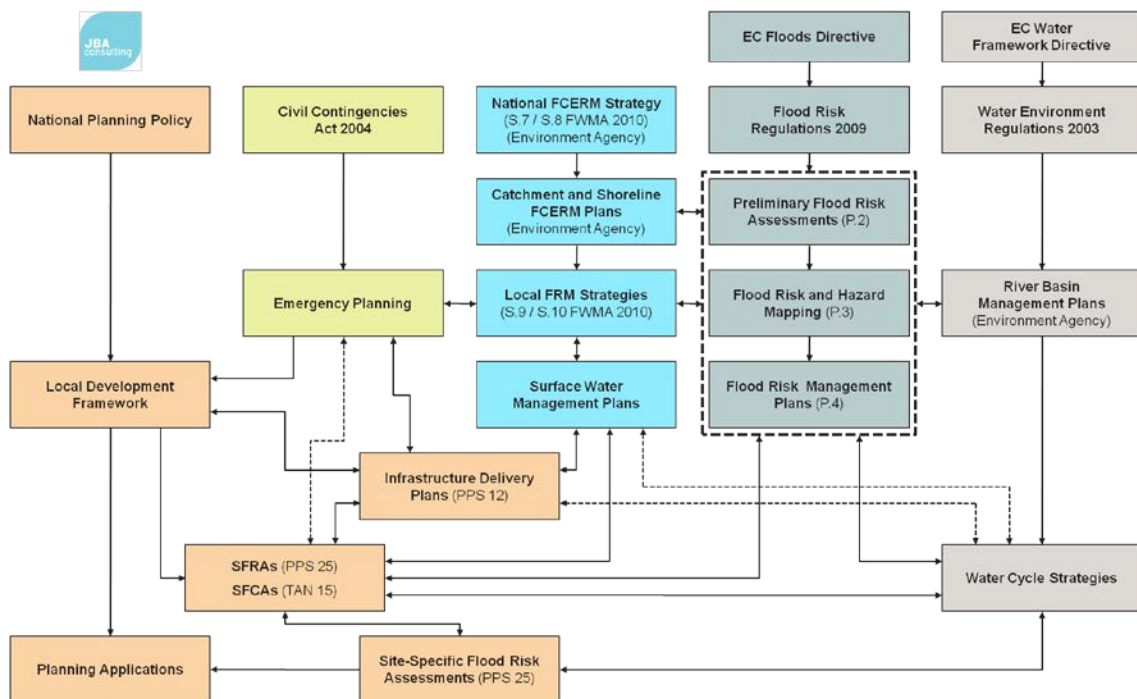
Figure 2.1 Local flood risk management – how does it all fit together? (reproduced with permission of JBA Consulting)

2.2 Flood and Water Management Act 2010

The Flood and Water Management Act (FWMA) aims to improve both flood risk management and the way we manage our water resources. It also assigns specific responsibilities to "risk management authorities" for different sources of flooding. This includes a new lead role for local authorities in managing local flood risk and a strategic overview/oversight role for all flood risk in England/Wales for the Environment Agency.

The FWMA requires a LLFA to develop, maintain, apply and monitor a strategy for local flood risk management in its area. As well as meeting local needs, the local strategy must be consistent with the national flood and coastal erosion risk management strategy developed by the Environment Agency.

2.2.1 Local flood risk management strategies

The production of a local flood risk management strategy for each LLFA area is a key output required by the FWMA. The local strategy contains compulsory elements that provide a useful framework for addressing duties and responsibilities to be delivered by LLFAs. Sections 9 and 10 of the FWMA set out the requirements for the local strategies in England and Wales respectively.

LLFAs must develop, maintain and apply the local strategy, including an assessment of local flood risk. Accordingly it is imperative that the formulation of a method and tools to assess flood risk reflects the needs of the local strategy and the requirement to be consistent with the national strategy. The local strategy will not be secondary to the national FCERM strategy; rather, it will have distinct aims to manage local flood risks important to local communities. The local strategies will need to build on information such as national flood risk assessments and should apply consistent risk-based principles across different local authority areas and catchments.

Local strategies need to balance the needs of the communities, the economy and the environment. The strategies must address the issues of local flood risk that exist now and in the future and provide information that enables communities to have a greater say in the actions required to deal with the causes and consequences of flooding. In broad terms, local flood risk management strategies should encourage more effective flood risk management by boosting partnership working.

Local Government Association (2011) has published a framework to help LLFAs develop their local flood risk management strategy. This framework is structured to inform LLFAs of the key local flood risk issues that should be considered and encourages them to balance the needs of communities, the economy and the environment when making risk management decisions.

The local flood risk management strategy should:

- Ensure a clear understanding of local flood risk, so that investment in risk management can be prioritised more effectively.

- Set out clear and consistent plans for risk management so that communities and businesses can make informed decisions about the management of residual risk.

- Encourage innovative management of flood and coastal erosion risks, taking account of the needs of communities and the environment.

- Form links between the local flood risk management strategy and local spatial planning.

- Ensure that emergency plans and responses to flood incidents are effective and that communities are able to respond properly to flood warnings.

- Help communities to recover more quickly and effectively after incidents.

2.3 Flood Risk Regulations 2009

The aim of the Flood Risk Regulations (the Regulations, SI 2009/3042) is to reduce the risk of flooding by reducing the probability and/or consequences of floods.

The Regulations transpose into domestic law the provisions of the European Commission Floods Directive (2007/60/EC) and came into force in England and Wales on 10 December 2009. They establish four well-defined stages of a flood risk management cycle:

1. Preliminary Flood Risk Assessment

2. Identifying Flood Risk Areas

3. Flood Hazard and Flood Risk Maps

4. Flood Risk Management Plans

2.3.1 Clarification of responsibilities

LLFAs are responsible for assessing risk from sources of flooding other than main rivers, the sea and reservoirs. In particular this includes surface runoff, groundwater and ordinary watercourses and any interaction these have with drainage systems and other sources of flooding including sewers. LLFAs therefore need to consider interactions in their assessment of flood risk, such as where an ordinary watercourse floods due to high water levels in a receiving main river.

In England, the LLFA is the unitary authority for the area, or if there is no unitary authority, the county council. In Wales, the LLFA is the county council or the county borough council.

The Environment Agency is the competent authority for managing risk from main rivers, the sea and large raised reservoirs. The Environment Agency must review, collate and publish the outputs of the Regulations.

This clarification of responsibilities was recommended by Sir Michael Pitt's independent review into the summer flooding of 2007 (Pitt, 2008) and is in line with new obligations set out in the FWMA. Both the Regulations and FWMA emphasise the importance of sharing information with partners.

2.3.2 Part 2: Preliminary Flood Risk Assessments

The preparation of Preliminary Flood Risk Assessments (PFRAs) is the first activity to be performed in accordance with the Regulations. It is a screening exercise which involves collecting information on past (historic) and future (potential) floods, assembling it into a Preliminary Assessment Report, and using it to identify Flood Risk Areas which are areas where the risk of flooding is deemed significant. The Environment Agency issued LLFAs with PFRA guidance and indicative Flood Risk Areas (based on a method and criteria produced by Defra and Welsh Government) for England and Wales using national datasets in December 2010. LLFAs reviewed the indicative Flood Risk Areas and amended them where better local information was available in the Preliminary Assessment Report. The deadline for LLFAs to submit their preliminary assessment report to the Environment Agency was 22 June 2011.

2.3.3   Part 3: Flood Hazard Maps and Flood Risk Maps

The PFRA process will feed into the next stage of the Flood Risk Regulations to produce Flood Hazard Maps and Flood Risk Maps for identified Flood Risk Areas.

Flood Hazard and Flood Risk Maps must be prepared in relation to sources of local flood risk for each Flood Risk Area identified as part of the PFRA process. These maps will help boost understanding of the flood risk at these locations. LLFAs need to submit their maps to the Environment Agency by June 2013.

2.3.4   Part 4: Flood Risk Management Plans

The Regulations require that Flood Risk Management Plans are put in place for each Flood Risk Area. These plans will set objectives and measures to help manage flood risk. The plans will also link to the local strategies required by the FWMA. Where available, Surface Water Management Plans (SWMPs) are expected to meet the majority of plan requirements (see below). Flood Risk Management Plans need to be submitted to the Environment Agency by June 2015.

This "overlap" with other flood risk assessments highlights the benefit of establishing integrated work practices and frameworks that generate long-term efficiencies (stages 1-4 are repeated on a six-year cycle), avoid unnecessary duplication and prevent abortive work. Integrated working also encourages and maximises the benefits from continued close partnership within and between local authorities, the Environment Agency and Water and Sewerage Companies (WaSCs), to achieve a shared understanding and co-ordinated management of flood risk.

2.4   Surface Water Management Plans

A Surface Water Management Plan (SWMP) is a plan which outlines the preferred surface water management strategy in a given location and is developed by LLFAs in consultation with local partners responsible for surface water management and drainage. In this context, surface water flooding describes flooding from sewers, drains, groundwater, and runoff from land, small watercourses and ditches that occurs as a result of heavy rainfall (Defra, 2010).

A number of SWMPs are currently underway in England, including 46 priority locations funded by Defra in 2009 and 18 Early Action SWMPs announced in March 2010.

The process of working together as a partnership is also designed to encourage the development of integrated solutions and practices to mitigate flood risk. SWMP studies will vary to meet local needs and circumstances, and so the current *Surface Water Management Plan Technical Guidance* (Defra, 2010) offers a flexible approach that will allow LLFAs to undertake a SWMP study tailored to their requirements. The SWMP Technical Guidance is based on a generic approach to evidence, which is risk-based decision-making and is structured into four phases described below.

2.4.1   Phase 1: Preparation

This phase includes establishing a partnership, setting objectives and scoping the study, including a screening exercise to check what local information is available. Partners should agree the level of risk assessment at which the SWMP study starts, based on the objectives, current knowledge and availability of information.

2.4.2 Phase 2: Risk assessment

A risk-based approach should be adopted to assess surface water flooding. There are three tiers of risk assessment identified in the guidance:

1. The risk assessment is likely to begin with a **strategic assessment** to give a broad understanding of local flood risks. The strategic assessment focuses on identifying areas more vulnerable to surface water flooding for further study.

2. The **intermediate assessment**, where required, will identify flood hotspots in the chosen study area, obvious mitigation measures, and any requirements for a detailed assessment.

3. A **detailed assessment** of surface water flood risk may be required to provide a greater understanding of flood risk and to test potential mitigation measures.

Outputs from the strategic, intermediate and/or detailed assessment should be mapped and communicated to all those involved including spatial planners, local resilience forums, and the public. These phases are directly relevant to PFRAs, providing opportunities for efficiencies and avoidance of duplication of effort.

2.4.3 Phase 3: Options

In this phase, a range of flood risk alleviation options is identified by consulting with partners. Unfeasible options should be eliminated. The remaining options are developed and tested for their relative effectiveness, benefits and costs. The purpose of this assessment is to identify the most appropriate mitigation measures which can be agreed and taken forward to the implementation phase.

2.4.4 Phase 4: Implementation and review

Phase 4 involves preparing an action plan based on the evidence gained from previous phases, carrying out the agreed actions and monitoring their implementation. Once the options have been implemented they should be monitored to assess the outcomes and benefits, and the SWMP should be periodically reviewed and updated where required.

2.5 Potential value of this project

As Sections 2.2-2.4 show, the risk assessment activities carried out as part of local flood risk management strategy, Flood Risk Regulations-related studies and SWMPs have much in common. An integrated and consistent approach to risk assessment can assist local decision-making and communication of flood risk through these different plans and strategies. For this reason, there is a clear need for a flexible risk assessment method, based on consistent principles and structured within a generic risk-based framework. Implementation of such an approach would support partnership working; reduce the likelihood of inconsistencies between flood risk assessments; and enable efficient and effective comparison of results across different study areas or spatial scales within the catchment area. It is envisaged that the outputs from this project will meet this basic requirement by providing a framework and methods for local flood risk assessments of tools and data to support its implementation.

3 Framework for local flood risk assessment

3.1 Risk concepts

The basic concept of risk combines the probability of a hazard with its consequences (see Defra/Environment Agency, 2002). This basic calculation may include a number of layers of information and can be taken as a form of generic framework, as shown in Figure 3.1.
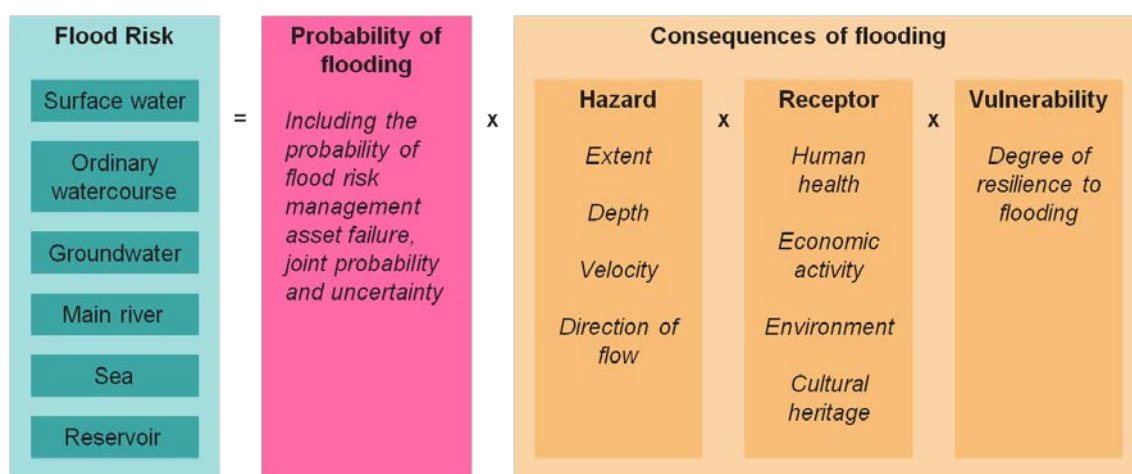
Figure 3.1 Generic framework for flood risk assessment

A simple risk assessment may consider fixed event scenarios where the probability of each scenario is estimated separately and the consequences are calculated deterministically. For example, the event scenario may be a rain storm that has a one in 100 chance of occurring in any given year (or a one per cent annual probability of flooding) and the consequences may be expressed as economic damages. Clearly, a risk assessment of this type depends on the chosen scenario and does not allow for the chances and consequences of more or less severe events. Such an approach provides an incomplete picture of the risk.

Risk-based methods used by the Environment Agency for rivers and coasts (Defra/Environment Agency, 2006) therefore seek to express the risk posed by the probabilities and consequences of any flood event, rather than a single, fixed event scenario. This involves representing all possible flooding events or a representative sample of all possible events. For local flood risk, the number of such events could be very large when taking into account possible rainfall patterns, the performance of the drainage system (including unpredictable factors such as blockages) and potential interactions with rivers, smaller watercourses or the sea.

Some research (HR Wallingford, 2009) has explored models of drainage systems and local flooding that could incorporate some of these complexities whilst using approximate hydraulic models, but consultation with professional partners during Phase 1 indicated that these approaches are currently beyond the technical capacity of

most LLFAs (see also Section 4.5). Local detail is considered important and, therefore, where detailed hydraulic models or datasets have been developed, there is a strong motivation to use them within the risk assessment process. However, the complexity and run time costs for such models tends to mean that, for practical purposes, only a limited number of event scenarios can be run.

Where it is only possible to represent a small number of possible events (due to programme/cost constraints, for instance), the probability analysis carries greater uncertainty, and this uncertainty is not fully quantified. However, a scenario-based approach is a valid way to help understand risk where there are uncertainties that are difficult to quantify. A good example of this is in climate change projections. Here, uncertainties about future greenhouse gas emissions mean that even sophisticated models such as the latest UK climate projections (UKCP09) make use of alternative emissions scenarios that are not associated with a probability.

This project therefore focuses on more accessible, scenario-based approaches for local flood risk assessment, although it does consider the possibility of using more sophisticated, probabilistic risk modelling tools in the future.

3.2   A simple, practical local flood risk framework

The interim methodology developed during Phase 2 of this project (described in SC070059/SR2) set out a three-level risk assessment framework that was aligned with the tiered approach taken by the Environment Agency in its RASP methods for rivers and coasts. However, the "high", "intermediate" and "detailed" levels of assessment within RASP are conceptually different from those identified in the Defra (2010) SWMP Technical Guidance, which are more closely associated with the spatial and process representation detail of the underlying hydraulic models. LLFAs are more familiar with the SWMP Technical Guidance and so, to remove any confusion, the project has concentrated on a **"scale-less" risk assessment approach that uses common principles and methods but can be used with information at different levels of hydraulic detail and spatial scale**.

Two cases will encompass most local authority users, as follows:

1. Those working with default information such as Environment Agency flood maps and the National Receptor Dataset - see Figure 3.2.

2. Those working with additional local information such as flood risk mapping, drainage system models, asset registers or historic flood reports - see Figure 3.3.

In the short to medium term local authorities are not likely to carry out sophisticated probabilistic risk modelling (the full analysis outlined in Figure 3.1). Our scale-less approach offers the required flexibility for flood risk management partners to apply increasing levels of detail in areas of significant risk or areas of local interest. Here, "detail" of spatial resolution and/or representation of flooding processes will be included within the models and datasets LLFAs want to use; they can also choose which flood probabilities to consider (for example, chosen for a limited set of design events or determined analytically through rigorous, structured sampling of the whole flood risk system).

This flexible approach to risk assessment also supports local decision-making on how the consequences of flooding are assessed. Simple measures of adverse flood consequence are discussed in Section 4.3.4, such as number of residential properties or critical services flooded, that are easy to calculate and apply consistently across the risk assessment framework. Alternatively, if the prerequisite data is available, LLFAs

can undertake more comprehensive economic damage and receptor vulnerability assessments down to the scale of individual receptors (such as properties, assets, see Section 4.4) within the same framework.

Flood Risk		Probability of flooding		Consequences of flooding				
				Hazard	x	**Receptor**	x	**Vulnerability**
Surface water	=	*Events modelled in flood map data*	x	*Flood outlines from Environment Agency Flood Map products*		*Human health*		*No default data set*
Groundwater						*Economic activity*		
Main river						*Environment*		
Sea						*Cultural heritage*		
Reservoir								
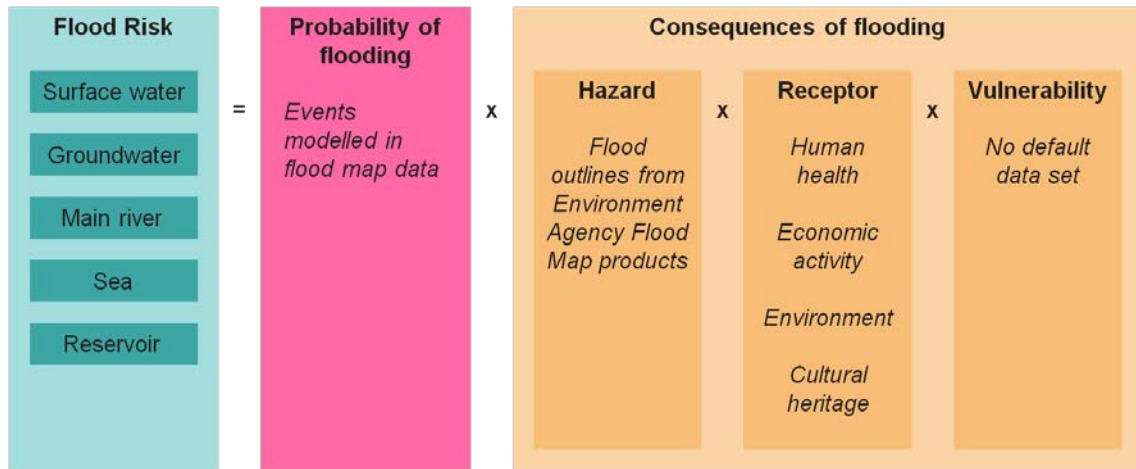
Figure 3.2 Framework for local flood risk assessment: default information

Flood Risk		Probability of flooding		Consequences of flooding				
				Hazard	x	**Receptor**	x	**Vulnerability**
Surface water	=	*Including the probability of flood risk management asset failure, and exceptionally joint probability and uncertainty*	x	*More detailed, local modelling of extent, depth, velocity, direction of possible floods*		*Human health*		*Property and asset threshold levels*
Ordinary watercourse						*Economic activity*		
Groundwater						*Environment*		*Depth-damage functions*
Main river						*Cultural heritage*		
Sea								
Reservoir								

Figure 3.3 Framework for local flood risk assessment: additional local information

4 Methods for local flood risk assessment

4.1 Introduction

Methods for local flood risk assessment can be presented in terms of the level of knowledge, models and data required for their implementation. Here, we have split them into those that can be adopted by:

- **any user** with access to national flood risk datasets provided by the Environment Agency (Section 4.3);

- **some users** with locally-available hydraulic models and data (Section 4.4);

- **few users** with potentially complex hydraulic models, advanced risk assessment tools and research capability (Section 4.5).

This section seeks to describe and demonstrate methods accessible to each type of user using typically-available information. It also identifies where local input is a basic requirement or would substantially improve the quality of risk assessment outputs.

4.2 Basic requirements

The methods described below have been developed to meet a number of basic requirements that emerged from the Phase 1 consultation with LLFA-led flood risk management partnerships. According to these users, the methods should:

- **Be simple to understand and apply**. They should be reproducible (if required) by all local FCERM partners.

- **Be implemented by LLFAs** to ensure the desired transparency on the source and quality of input data, and establish confidence in the final risk assessment outputs.

- **Use the best available information wherever possible**. This could be "default" flood risk datasets, such as the Environment Agency's fluvial and coastal Flood Map, surface water flood maps and National Receptor Dataset, or LLFAs' own hydraulic models and receptor data held locally. LLFAs have determined "locally agreed surface water information" as part of the PFRA process, which sets out which national and local surface water datasets best represent local conditions. LLFAs must be able to make use of local information.

- **Be independent of spatial scale and flood probability**. Users must be able to apply the same methods regardless of the size of study area, spatial detail required and range of flood probabilities under consideration.

- **Help LLFAs to meet legislative requirements and inform plans and strategies in a more consistent manner** (see Section 2).

- **Be able to investigate the impacts of changes to the physical system** (such as climate change, urban creep, new development, introduction of

flood risk management measures). The outputs from the consequence assessment process should support options appraisal and provide evidence to inform investment decisions.

- **Add to the evidence base to support balanced local decision-making**. The framework, methods, and prototype software tools developed must provide the evidence and be useful to local authorities as democratically-elected organisations who balance the economic, social and environmental consequences of flooding.

4.3   Methods that can be used by anyone

An important first step for many LLFAs and their FCERM partners will be to understand the distribution of flood risk across their respective administrative areas and identify and prioritise locations requiring more detailed investigation. The outputs from such a screening exercise can inform a wide range of flood risk-related studies, such as Level 1 Strategic Flood Risk Assessments (SFRA), Strategic Flood Consequence Assessments (SFCA), local strategies and SWMPs, as well as strategic planning activities including emergency planning, local resilience, capital investment and asset management.

4.3.1   Flood risk indicators

The screening method proposed here is simple to follow. It is based on intersecting national flood outlines and receptor data within a geographical information system (GIS) to calculate flood risk indicators (FRIs). Various guidance and scoping documents have recommended FRIs as a transparent means for assessing potential adverse consequences to human health, economic activity, environment and cultural heritage for regional flood risk appraisals (Adamson *et al.*, 2008; CLG, 2008; OPW, 2008; Hankin *et al.,* 2009). They represent measures of the consequences of flooding that are easily understandable, such as the number of properties in a flood outline for a given "reporting unit" area, typically a regular spatial grid (Environment Agency 2010a). Accordingly, FRIs can provide an efficient, intuitive basis for identifying areas at significant risk across multiple flood sources and impact groups.

Figure 4.1 demonstrates the approach for calculating the three principal types of flood risk indicator. These are:

- a simple **count** of property or asset points in an outline (note that properties can also be identified by their footprint/outline which is discussed in Environment Agency (2010b));

- the **length** of key infrastructure within an outline;

- the **area** of a special designation within an outline.

Individual FRIs can be combined to give an overall measure of the potential adverse consequences associated with a mapped flood outline.

(a) Flood outline within one-km grid square reporting unit
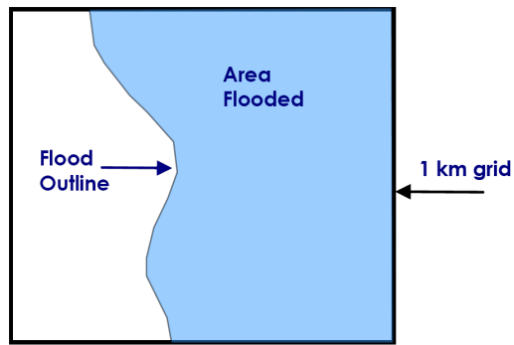
(b) A count of point receptor data
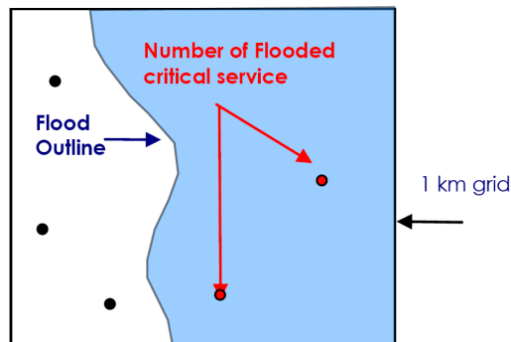
(c) A length measure of polyline receptor data
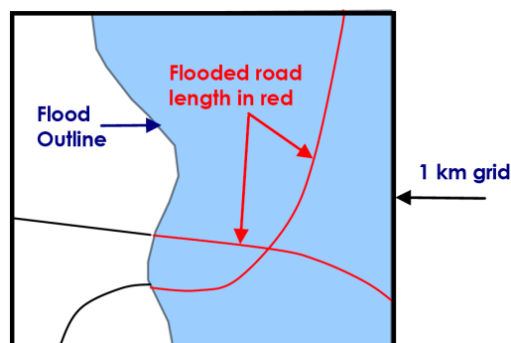
(d) An area measure of polygon receptor data
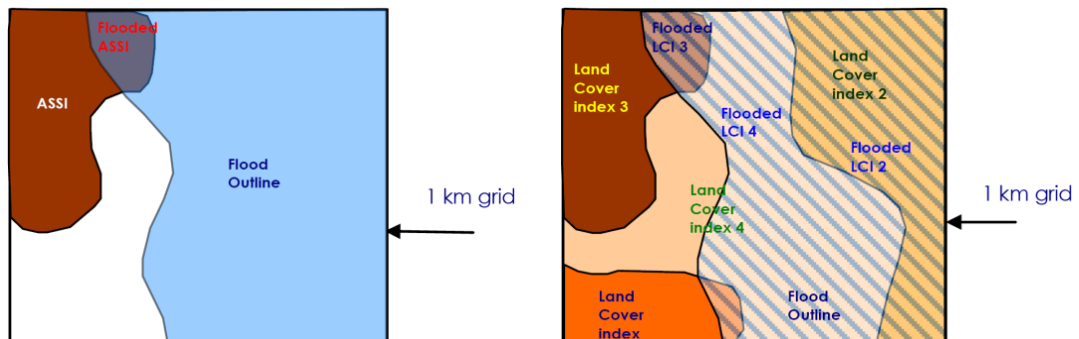
Figure 4.1 Point, polyline and polygon-based flood risk indicators

4.3.2   Calculating flood risk indicators

The GIS analysis required to calculate flood risk indicators can be run in four steps using functionality available within most GIS software.

Step 1 – Identify/generate reporting unit polygons and pre-process source datasets

Users must first identify or generate a set of reporting unit polygons for which counts, lengths and areas of affected receptors will be reported. Reporting units can be regular grids, such as that used to support the identification of indicative Flood Risk Areas as part of the England and Wales PFRA, or they can be irregular catchments or administrative units (such as districts, wards or parishes). Each reporting unit is required to be a single polygon object with a unique identifier.

Depending on the GIS software being used to make the FRI calculation, it may be possible to pre-process the source datasets globally, that is, clip, union or intersect the flood outline and receptor data to the reporting unit coverage in a single step. However, as the analysis is ultimately carried out on a reporting unit-by-reporting unit basis, this section describes the process for calculating FRIs within individual reporting units.

In order to calculate the desired FRIs, it is often necessary to filter the receptor data. For example, as part of the England and Wales PFRA, FRIs were calculated for residential and non-residential properties using the National Receptor Dataset (NRD) Property Point dataset. However, by default, all property types are combined within the Property Point dataset meaning that data relevant to each FRI will need to be filtered via their attributes. This process is described in detail in Environment Agency (2010a).

Step 1 may require the extraction of several subsets of receptor data from the original source and therefore the creation of new GIS files. Strong data management throughout the calculation process is therefore essential.
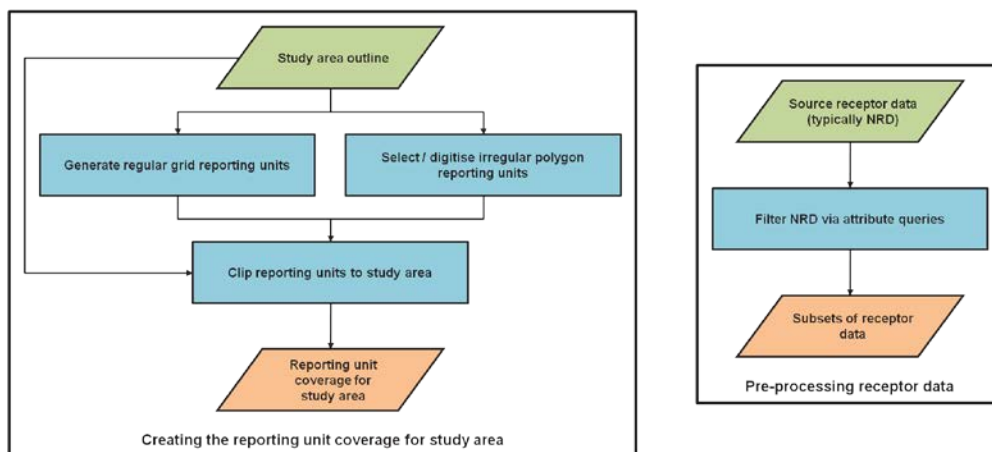
Figure 4.2 Step 1 of calculating flood risk indicators

Step 2 – Clip flood outline and receptor data to the extent of each reporting unit

Next, flood outlines that describe the hazard affecting chosen receptors are clipped to the extent of each reporting unit (see Figure 4.1a for example). The same process is also undertaken for each of the receptor datasets, such as property points, road and rail polylines and designated environmental area polygons (see Figure 4.1b - Figure 4.1d). This results in each reporting unit polygon having a set of clipped flood outlines and receptor data available for intersection analysis (Step 3).
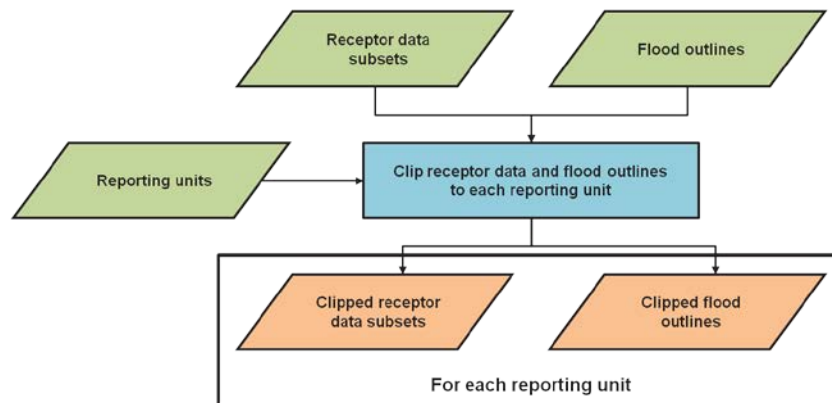
Figure 4.3 Step 2 of calculating flood risk indicators

Step 3 – Spatial intersections to calculate basic flood risk indicators

The third step is to identify and record the spatial relationship between the flood outlines and receptor data within each reporting unit. For point data, the number of points that intersect the flood outline is calculated (see Figure 4.1b) and this value is added to the attributes of that reporting unit as a new field. If required, this step is repeated for all lengths of polyline (see Figure 4.1c) and areas of polygon (see Figure 4.1d) data that intersect the flood outlines within the same reporting unit.
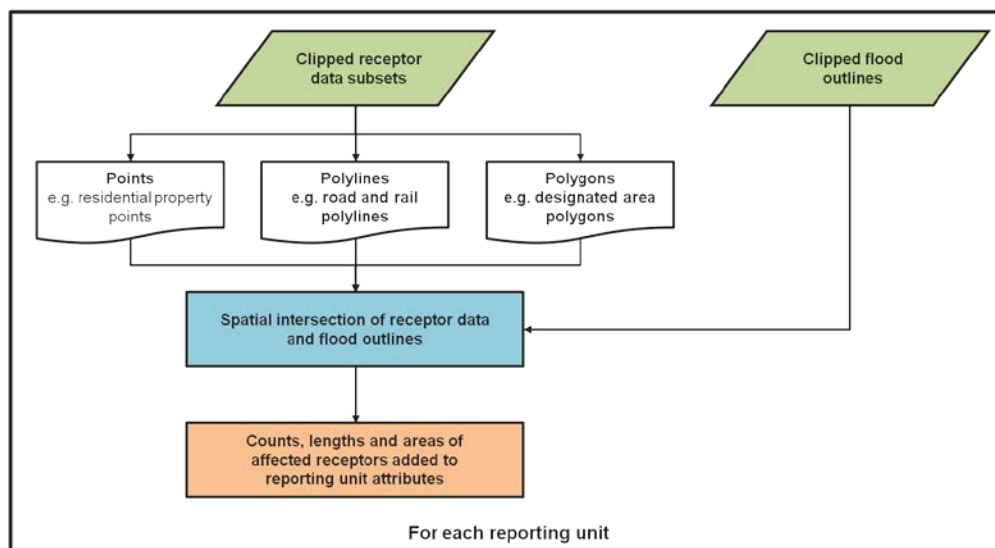
Figure 4.4 Step 3 of calculating flood risk indicators

Step 4 – Calculate extended flood risk indicators

FRIs can simply be counts, lengths or areas of the various geometries that fall within each of the reporting units, or may require additional processing to produce the final indicator value. For example, for the England and Wales PFRA, the number of people at risk of flooding within each 1 km square reporting unit was calculated by multiplying the count of residential properties flooded by 2.34.

Post-processing may be necessary to sum related subsets of data into a single composite FRI. For example, the count of critical services used within the PFRA analysis is actually the sum of counts of affected hospitals, police, fire and ambulance stations, schools, electricity installations and sewage works, all of which have been filtered individually from the NRD Property Point dataset by means of attribute queries. Once calculated, the sum total is added to the reporting unit as a new attribute and can be taken into account in the subsequent consequence analysis.
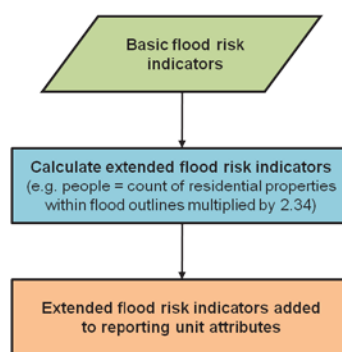
Figure 4.5 Step 4 of calculating flood risk indicators

4.3.3   Relevant datasets

The following national (or "default") flood risk datasets are currently available from the Environment Agency for this type of analysis.

Flood Map (Fluvial and Coastal)

This well-established product identifies areas at risk from fluvial and coastal flooding (ignoring the presence of flood defences). The map data comprises Flood Zone 3 (1 per cent annual probability fluvial, 0.5 per cent annual probability coastal) and Flood Zone 2 (0.1 per cent annual probability fluvial, 0.1 per cent annual probability coastal).

Surface water flood maps

Released in autumn 2010, the Flood Map for Surface Water (FMfSW) is now the primary source of nationally-derived information on surface water. The new mapping is based on better surface data and improved scientific assumptions for infiltration and sewer drainage (see Environment Agency (2010b) for further details). The previous Areas Susceptible to Surface Water Flooding (AStSWF) map provides further supporting information, as it may represent certain locations local conditions better than the new map (for example in areas with very low drainage capacity). Neither map is intended to be definitive, but provides information to support local flood risk

management in the absence of any better information. When referred to together these data are known as the Environment Agency surface water flood maps.

The FMfSW models the 3.33 and 0.5 per cent annual probability rainfall events, presented as two flood outlines. The information is classified into two bands, "shallower" (depths between 0.1-0.3 m) and "deeper" (depth greater than 0.3 m).

The AStSWF mapping describes flooding for the 0.5 per cent annual probability event only and uses different assumptions regarding rainfall storm duration and natural and urban drainage processes (see Environment Agency (2010c) for further details). The data is presented as three susceptibility bands: "less" susceptible (depths between 0.1-0.3 m), "intermediate" susceptibility (depths between 0.3-1.0 m) and "more" susceptible (depths greater than one metre).

For both surface water flood maps, the classification was intended to simplify interpretation of the map data for non-expert users and prevent over-interpretation of uncertain model results.

As part of the PFRA process, LLFAs were asked to review, discuss, agree and record, with the Environment Agency, water and sewerage companies, Internal Drainage Boards (IDBs) and other interested parties, what surface water flood data best represents local conditions. This is known as "locally agreed surface water information" and is described in Environment Agency (2010d).

The locally agreed surface water information could be a single national surface water flood map or a composite product incorporating local modelled data where available. Different decision-making scenarios (such as land use planning or emergency planning) may need different data (such as worst case flood extents). Consequently, the most representative surface water data may be different for different purposes, even within one location.

Groundwater flood maps

Four national datasets provide information on susceptibility to groundwater flooding and are summarised in Environment Agency (2010a). Each has limitations, which may include: cost, resolution, coverage (for example, England only), classifications (it may or may not be linked to an estimated flood probability) and hydrogeological coverage (for example, only chalk; or only consolidated aquifers).

Also, and perhaps most importantly for the methods described here, these datasets typically cover large areas of land, and only isolated locations within the overall susceptibility outline are actually likely to suffer the consequences of groundwater flooding. This means that GIS-based flood risk indicator calculations, such as property counts, will not produce sensible results for these maps as the numbers of affected receptors will be enormous compared to other flood sources/maps.

National Receptor Dataset

The National Receptor Dataset (NRD, Defra/Environment Agency, 2009) is a consistent, single repository of data on receptors, which if flooded can cause potential harm to human health, economic activity, the environment and cultural heritage. It comprises geo-spatial data which has been cleared of intellectual property rights (IPR) issues for use by the Environment Agency and LLFAs. The NRD contains data on the location and type of buildings, critical infrastructure such as roads, critical services such as hospitals, agricultural land use, and designated environmental sites and heritage assets. However, although it represents a significant step forward, the information

contained in the NRD is not perfect and requires careful scrutiny by LLFAs to ensure the local accuracy of "default" receptor information. Indeed, LLFAs may wish to use locally-held alternatives to the NRD that have been compiled, for example, for spatial and emergency planning purposes. Alternatively, a composite dataset based on the best available local and national information may be used.

The NRD will not contain the detailed asset information held by LLFAs as required under Section 21 of the FWMA. Partners should therefore undertake a gap analysis and identify local infrastructure, assets and designated sites missing from the NRD. During this data assimilation process it will also be important to ensure that receptors are not "double counted" across multiple datasets.

4.3.4 Example flood risk indicators

From the datasets described above, a wide range of flood risk indicators can be calculated. Table 4.1 contains a number of example indicators to illustrate the generic FRI approach that can be organised into "impact categories" ("human health", "economic activity", "environment" and "cultural heritage") as per the PFRA Final Guidance (Environment Agency, 2010a).

Table 4.1 Example flood risk indicators

Flood Impact	FRI Name	Type	Example Calculation Method	Comments
Human Health	Residential properties	Count	Residential properties can be selected from the NRD where the MCM Code = 1 (see Environment Agency, 2010a). There are different methods for counting properties that use either arbitrary points within the buildings' footprints or the buildings' footprints themselves. The different methods are described in Environment Agency (2010e) and will produce very different estimates of the number of properties at risk (increased by a factor of 2-5 if using footprint polygons).	
	People	Count	Residential properties x 2.34.	Used to support the identification of indicative Flood Risk Areas as part of the England and Wales PFRA
	Critical services	Count	As per Annex 6 of PFRA final guidance (Environment Agency, 2010a).	Used to support the identification of indicative Flood Risk Areas as part of the England and Wales PFRA
Economic Activity	Non-residential properties	Count	As per Annex 6 of PFRA final guidance (Environment Agency, 2010a).	Used to support the identification of indicative Flood Risk Areas as part of the England and Wales PFRA
	Infrastructure network	Length	Select and combine road and railway polylines from the NRD.	
	Agricultural land	Area	Select relevant agricultural land classifications from NRD (e.g. all grades or only Grades 1, 2 and 3).	
Environment	Pollution	Count	Consider Pollution Prevention and Control (PPC) and Control of Major Accident Hazard (COMAH) sites. May need to be supplemented with data held by Local Resilience Forums.	Similar information supplied to LLFAs on the CD of supporting materials for PFRAs in December 2010

Flood Impact	FRI Name	Type	Example Calculation Method	Comments
	Designated environmental sites	Area	Consider Special Areas of Conservation (SAC), Special Protection Areas (SPA), Ramsar sites, and Sites of Special Scientific Interest (SSSI). May need to be supplemented with data held by local Environment Agency office.	Similar information supplied to LLFAs on the CD of supporting materials for PFRAs in December 2010
Cultural Heritage	Designated heritage assets	Count/ Area	Consider World Heritage sites, Scheduled Monuments (SMs), listed buildings, and registered parks and gardens. May need to be supplemented with data held by local planning authority.	Similar information supplied to LLFAs on the CD of supporting materials for PFRAs in December 2010

4.3.5   Identifying flood risk hotspots

FRIs help understand relative risk, but do not categorise risk as "low", "medium" or "high".

In theory, risk categories can be easily defined by LLFAs in terms of thresholded FRI values – for example, as part of the methodology to identify indicative Flood Risk Areas for the England and Wales PFRA, reporting units that contained more than 200 people at risk of flooding were classified as "places above the flood risk thresholds". However, in reality, the choice of thresholds will need to be carefully investigated, based around local understanding of how setting particular thresholds captures areas of known high risk for past or future floods. LLFAs will also need to consider their tolerance for risk and take into account other local political and flood risk management priorities. It is therefore inevitable that risk *categorisations* will vary between LLFAs because of the level and type of risk their communities face and local circumstances.

Setting local thresholds and categorising flood risk indicators serves two important purposes.

First, it can be used to simplify the spatial and statistical analysis of individual FRIs. This will assist with the understanding and communication of flood risk. For example, in Figure 4.6 and Figure 4.7, the two thresholds have been used to develop a simple "low – medium – high" classification and associated "traffic light" colour-coding scheme to improve the communication of distributed flood impacts. The examples given below show the number of residential properties flooded across Gloucestershire according to the 0.5 per cent annual probability Flood Map for Surface Water.
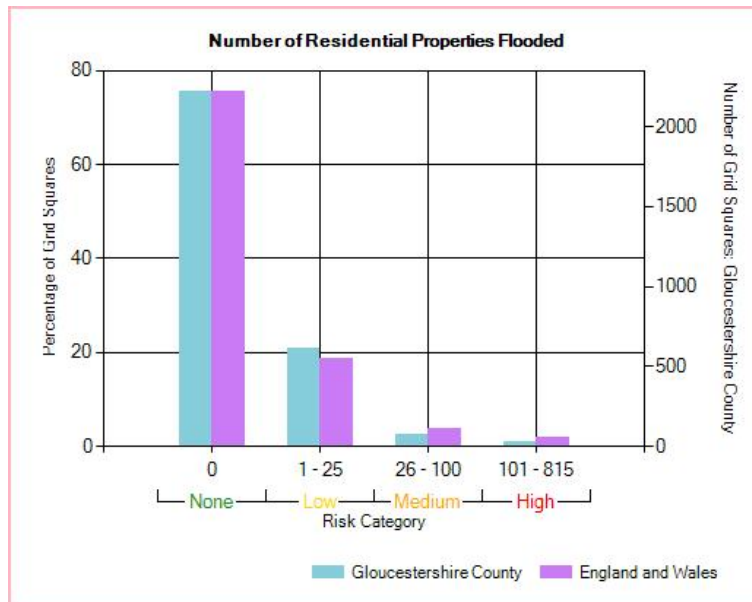
Figure 4.6 Example histogram distribution of "number of residential properties flooded" FRI across Gloucestershire where the upper and lower thresholds are 100 and 25 properties respectively
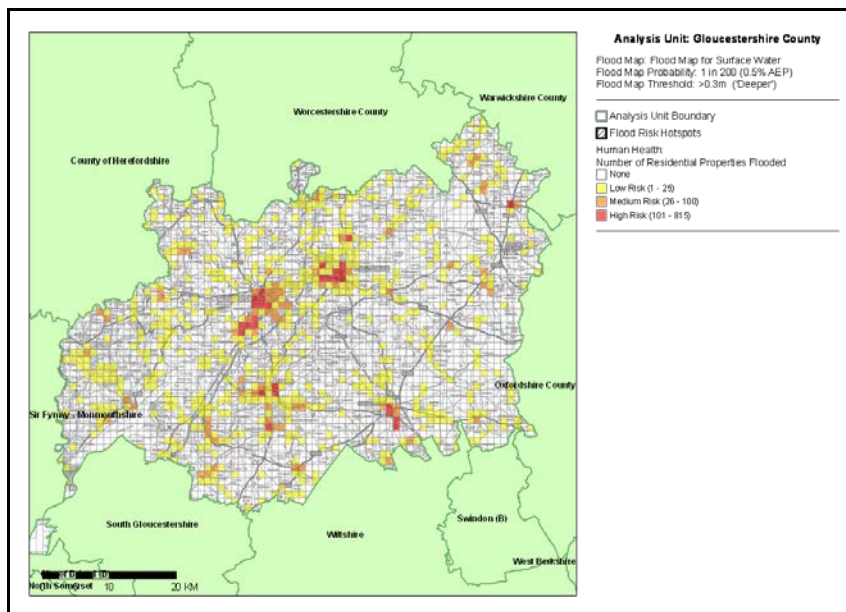
Figure 4.7 Example spatial distribution of "number of residential properties flooded" FRI across Gloucestershire where the upper and lower thresholds are 100 and 25 properties respectively

Second, this approach can help to objectively identify flood risk "hotspots" that may require priority action or further, more detailed investigation during subsequent studies. Here two methods are proposed to prioritise work, a "single threshold" and "dual threshold" approach, which are illustrated for four generic FRIs in Figure 4.8.

- Here there are two risk classification thresholds, "upper" and "lower".
- **Rule 1**: If the upper threshold is exceeded for any FRI then that square reporting unit becomes a flood risk hotspot.
- **Rule 2**: If the lower threshold is exceeded for any 2 FRIs in the square reporting unit, that also a flood risk hotspot.
- Rule 2 results in combining the impacts of more than 1 FRI in the hotspot analysis.
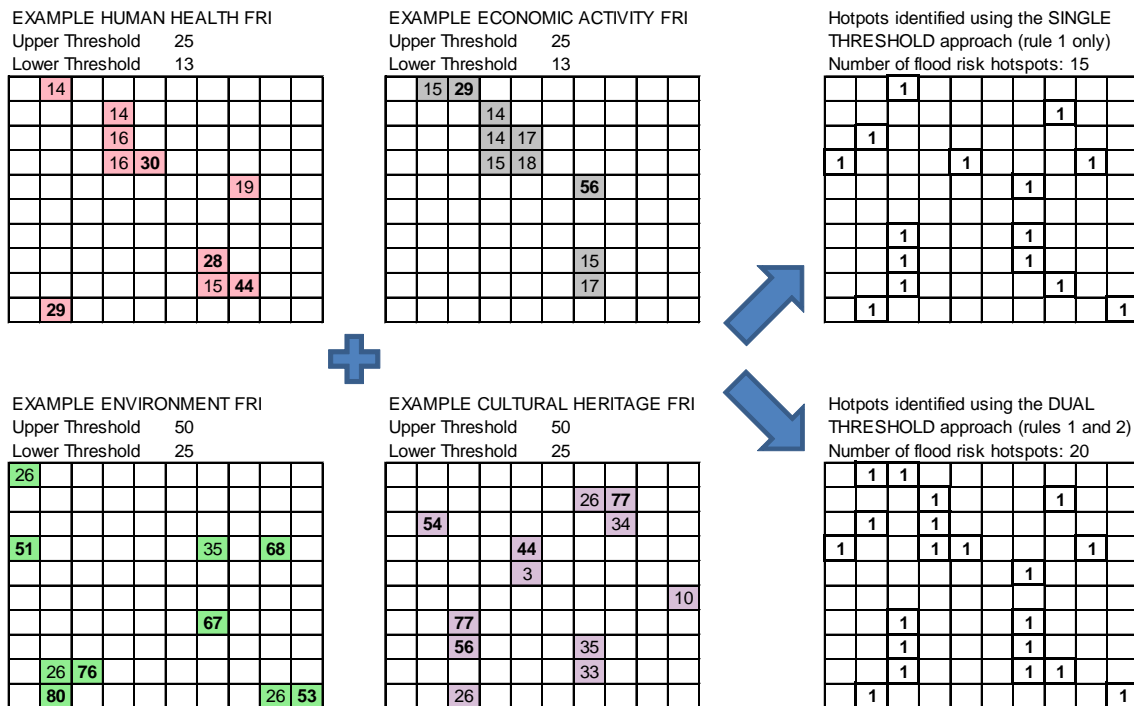
Figure 4.8 Combining flood risk indicators and defining flood risk hotspots

From Figure 4.8, it can be seen that a different number of flood risk hotspots are identified for the same thresholds in each case. This demonstrates the effect of rule 2, which additionally considers information in the "medium" risk category (i.e. between the upper and lower thresholds) in the hotspot analysis. Whichever approach is selected, thresholds can then be set to define/identify flooding hotspots based on a locally acceptable level of flood risk.

Using the same (or different) thresholds, hotspots can also be produced for flood maps that correspond to other sources of flooding, which may then be amalgamated and refined based on local knowledge to define "composite" risk hotspots. While these composite hotspots provide a simple assessment of the risk of flooding from multiple sources, they do not explicitly consider the combined risk from, or interactions between, flooding from different sources. The method described here will only calculate damages on a flood map by flood map basis (regardless of source) and not combine flood depth information from the different sources of flooding. However, another Defra/Environment Agency FCERM project, *Prototype Tool for Mapping Flooding from All Sources*, has developed a method and prototype software tool, mapping all sources tool (MAST) that may be of relevance here (see Environment Agency publications website for further details).

MAST enables sets of flood mapping data representing flooding from different sources (including coastal, river, surface water, with and without asset failure, reservoir inundation) to be combined to produce a flood map for multiple sources of flooding. MAST uses a probabilistic method to combine sources of flooding and displays overall probabilities, individual source contribution and uncertainty. MAST and this project's methods and prototype tools could be used by users to calculate the probability and then calculate/displaying the consequence/risk of flooding.

4.3.6   Prioritising flood risk hotspots

Depending on the thresholds selected and the size of the study area and reporting units, it is possible to define large numbers of hotspots that can be difficult to differentiate from each other. Therefore, a simple, transparent method that allows rapid prioritisation of the identified hotspots would help the analysis.

The approach proposed here requires calculated FRIs to be assigned a "relative priority score" that reflects local political and flooding priorities. Scoring is therefore highly subjective but this is reasonable if it is to reflect the concerns of local partners and decision-makers that will understandably vary between LLFAs. The example shown in Figure 4.9 illustrates how an overall priority score is calculated for a single reporting unit. Overall priority scores are calculated by similar means for all reporting units across the study area and are then ranked to identify priorities for further investigation. This method has the advantage that the same relative priority scores can be applied whether the single or dual approach to hotspot identification is used.

- Each flood risk indicator is assigned a relative priority score.
- **Rule 3**: If the upper threshold is exceeded for a particular FRI (i.e. rule 1 in the previous figure) then that reporting unit is assigned the relative priority score associated with that indicator.
   If Rule 3 is applied below, then the value 1 is shown in the relevant FRI column.
- **Rule 4**: If the lower threshold is exceeded for any 2 or more FRIs (i.e. rule 2 in the previous figure) then that reporting unit is assigned half of the relative priority score associated with each indicator.
   If Rule 4 is applied below, then the value 0.5 is shown in the relevant FRI columns.
- An overall priority score is calculated for each reporting unit from the total of relative priority scores across all FRIs.

	RELATIVE PRIORITY SCORE (RPS)
FRI 1	5
FRI 2	2
FRI 3	1

Using the SINGLE THRESHOLD approach to defining flood risk hotspots

Example Hotspot Combinations	FRI 1	RPS	FRI 2	RPS	FRI 3	RPS	OVERALL PRIORITY SCORE (OPS)	RANK
1	1	5	0	0	0	0	5	3
2	1	5	1	2	0	0	7	2
3	**1**	**5**	**1**	**2**	**1**	**1**	**8**	**1**
4	0	0	1	2	1	1	3	4
5	0	0	1	2	0	0	2	5
6	0	0	0	0	1	1	1	6

Using the DUAL THRESHOLD approach to defining flood risk hotspots

Example Hotspot Combinations	FRI 1	RPS	FRI 2	RPS	FRI 3	RPS	OVERALL PRIORITY SCORE (OPS)	RANK
1	1	5	0	0	0	0	5	3
2	**1**	**5**	**0.5**	**1**	**0.5**	**0.5**	**6.5**	**1**
3	0.5	2.5	0.5	1	0.5	0.5	4	5
4	0	0	0.5	1	0.5	0.5	1.5	7
5	0.5	2.5	0.5	1	0	0	3.5	6
6	0.5	2.5	1	2	0.5	0.5	5	3
7	1	5	0	0	1	1	6	2

Figure 4.9 Prioritising flood risk hotspots

4.3.7   Quality assurance

In the previous sections, we outlined an easy-to-apply method for screening flood risk across broad geographical areas consistent with the Environment Agency's approach for defining indicative Flood Risk Areas. These methods also support the development of local strategies and SWMPs as they provide an assessment of flood risk in their area, using a consistent method with national and local information (where available). The method allows local political and FCERM priorities (relative reduction in the

adverse consequences of flooding for human health, the environment and economic activity) to be reflected objectively in the hotspots identified for further investigation.

However, it is important for LLFAs to carry out quality assurance of the results. LLFAs should review, and modify manually if necessary, the outputs from this approach using whatever local flood risk information is available. This local quality assurance step is particularly important as it is highly likely that any analysis based on national datasets will miss some areas of known high consequence, through poor description of the flood hazard itself and/or gaps in the NRD. This highlights the importance of gathering local knowledge from detailed studies/historic records and emphasises the importance of good data management.

4.4   Methods useful for some

More detailed risk assessments, in terms of geographic scale or representation of flood processes, can be undertaken in areas identified as "hotspots" for local flood risk, or where better information (hydraulic models and data) is available. The areas for more detailed assessments can be identified from the outputs of analyses similar to those described above, existing flood risk assessments, or where there are already known flooding problems. The purpose of more detailed assessments is to gain a better understanding of the causes and consequences of flooding, and to test the benefits of potential mitigation measures. Typically this is achieved through local modelling of surface and/or sub-surface drainage systems.

The methods outlined below can help LLFAs to understand the impacts of local flooding down to the scale of individual receptors (such as properties, critical services and infrastructure assets) with greater confidence. They rely on the availability of locally-produced depth information and allow economic damages and receptor vulnerability (degree of resilience to flooding) to be considered at much finer spatial scales than those supported by the national flood map datasets provided by the Environment Agency. As such, these methods enable a rational quantification of flood risk that can be used to investigate different flood risk management strategies through benefit-cost analysis.

The proposed methods are not tied to any particular model software, structure or output format. This is because, as discussed in Section 3, models will inevitably contain different types and levels of detail (such as spatial resolution, representation of source and pathway processes) that will be appropriate for local circumstances and requirements.

4.4.1   Locally available hydraulic models and data

Hydraulic models

Hydraulic models, such as those described in Annex C of the SWMP Technical Guidance (Defra, 2010), can provide a range of outputs that describe, either directly or indirectly, the hazard posed by local flooding (see Figure 3.3). However, it cannot be assumed that all LLFAs will have access to detailed hydraulic modelling tools/outputs.

Numerical simulation models can be expensive to develop and may be beyond the means or needs of some LLFAs. Indeed, many LLFAs are reliant on models developed by other flood risk partners (such as the Environment Agency, WaSCs and IDBs) to inform their detailed risk assessments. It is therefore important that the

provenance, quality and limitations of any third party model-based information are well understood, as partners' models will be developed in line with their own responsibilities, often to different specifications and for purposes other than flood risk assessment. An excellent checklist for assessing a model's "fitness for purpose", that is whether the model can be used to help make reliable and accurate decisions, is provided in Annex D of the SWMP Technical Guidance (Defra, 2010).

The use of local models should mean that flooding mechanisms and probabilities of flooding are better represented, resulting in higher quality risk assessment outputs than those using only national generalised modelling. Multiple scenarios can also be developed and tested, corresponding to traditional design scenarios for the present day system or future scenarios, such as climate change, urban creep, new development, or the impact of proposed flood risk management measures.

Receptor data

Another way to improve risk assessment outputs is through better quality receptor data. Better information on receptors in key areas, such as locations, critical thresholds, interdependencies, potential for disruption, can help the method. This will inevitably focus on "current" receptors in the first instance, but could also consider those associated with land use changes, future developments and other capital schemes. Potential sources of information for locally held receptor databases may include:

- Local Resilience Forums

- Highways and drainage departments

- Local planning authorities

- National Land and Property Gazetteer entries

- Utility companies (water, gas, electricity, telecommunications)

4.4.2   Property level depth analysis

While depth maps can be used to calculate flood risk indicators as described in Section 4.3.2, the real value of local depth information is that it allows economic damage and receptor vulnerability to be considered at a spatial resolution similar to the model grid. Damage/vulnerability assessments require representative depth information for individual receptors (such as properties, assets) and the outputs from 1D and 2D overland flow models are well suited to provide these data. However, with increasing model resolution and options for modelling urban environments, the process of determining a "representative" depth at each receptor is a source of considerable methodological uncertainty. It is this estimate of flood depth that is used in quantitative flood damage/vulnerability assessments and so its reliability and accuracy is critical to minimise uncertainty in the subsequent consequence analysis. Therefore, with no commonly agreed best practice guidance for depth analysis, it is important to record all assumptions, decisions and processing steps made throughout the depth analysis process as there are many grey areas that can have a significant impact on the results.

Different methods for extracting representative depth information are shown in Figure 4.10. The choice of method will depend on how the receptor features are described, both in the model itself (such as voids in the computational mesh, see Figure 4.10b, or "up-stands" of higher roughness, see Capita Symonds/Scott Wilson (2010)) and the subsequent consequence analysis (as single address points or polygon footprints). When using building polygons, there is no consensus on which descriptor of flood

depth is considered best practice or most representative; typically options maximum, mean or median could be chosen. The potential differences can be seen in Figure 4.10. **LLFAs must be aware that all these decisions will have a significant impact on the number of, and severity of hazard at, susceptible receptors**.

Methodological considerations aside, implementation of the different approaches is relatively straightforward within most GIS software. For example, depth information can be easily extracted using standard point or region inspection tools, although some software may require additional "extensions" to undertake the analysis efficiently (such as Spatial Analyst for ArcGIS or Vertical Mapper for MapInfo).

These techniques can also be used to interrogate velocity and hazard rating maps within/adjacent to receptors.
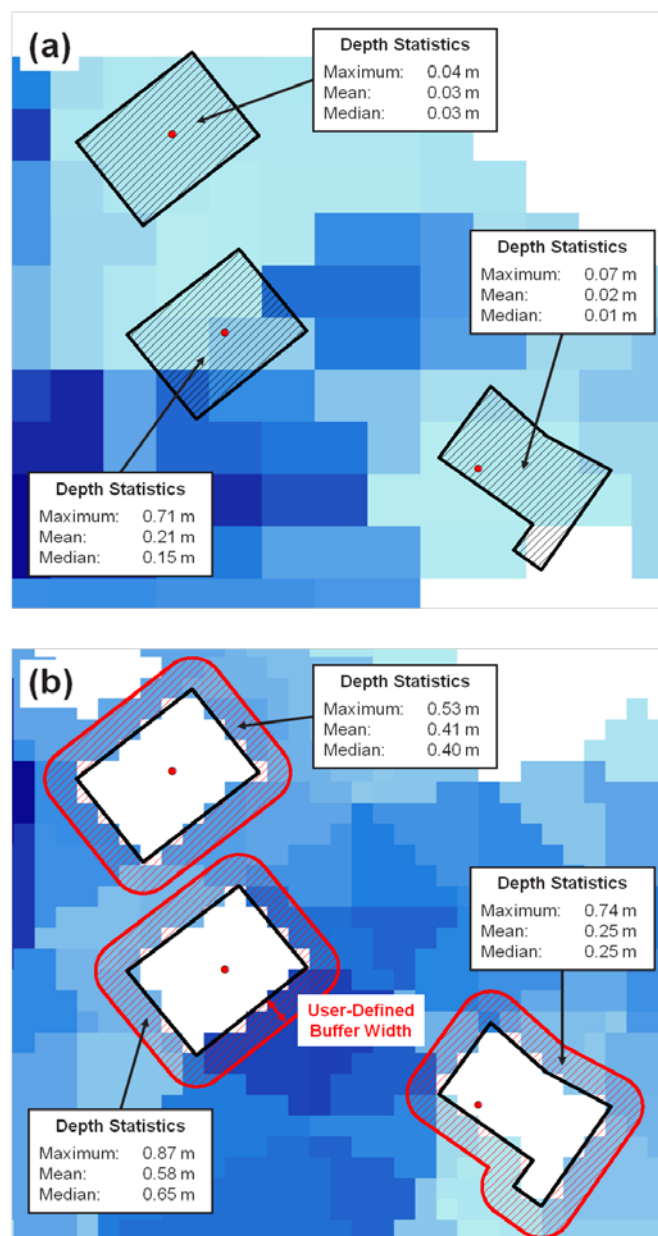

Figure 4.10 Property level depth analysis with buildings (a) included or (b) removed from the computational mesh. Building footprint polygons and NRD property points are shown as black outlines and red points respectively. The "analysis buffer" of user-defined width is displayed using a red hatching pattern.

4.4.3   Calculating damages

Depth data can also be used to estimate damages for different property types using well established depth-damage relations. Used previously for Catchment Flood Management Plans across England and Wales (Penning-Roswell *et al.,* 2005) these look-up tables have recently been updated as part of Defra/Environment Agency FCERM project, *Update of the Multi-Coloured Manual.*

A technical reference for anyone interested in calculating economic damages using the Multi Coloured Manual (MCM) depth-damage curves and NRD Property Point dataset is provided by HR Wallingford (2008). The HR Wallingford (2008) Technical Note also provides guidance on how to add/update locally held copies of the national property dataset in a consistent way.

Users can develop their own depth-damage functions following standard methods set out in Penning-Roswell *et al.* (2005) and Black *et al.* (2005). However, this can be expensive and time-consuming, and is only recommended for very high value properties that dominate local damage estimates and/or for large, mixed used sites such as hospitals, power stations and water treatment works.

The resulting damages may be analysed in a number of different ways, as maps, charts or summary tables (see Section 6.4), and the severity of impacts can be assessed under single or multiple model scenarios.

Methods for calculating flood damage to other receptors, such as people, critical infrastructure and the environment are also available and these are described in Annex E of the SWMP Technical Guidance (Defra, 2010).

4.4.4   Risk approximation and annualisation

The availability of multiple, probability-weighted depth grids allows annual average quantities of flood risk indicators to be calculated. Traditionally, damages are most commonly used to quantify flood risk (annual average damages) but any indicator can be used in theory (for example, annual average number of residential properties flooded). These values represent the notional long-term average (statistically speaking the "expectation") of the consequences of flooding in any given year and provide an objective basis for comparing flood risk between different areas.

Annual average quantities can be approximated with varying levels of statistical rigour (see Section 2.2 of interim methodology report (SC070059/SR2) for a full discussion). An approach based on discrete event scenarios is more practical for use by LLFAs than the fully probabilistic RASP HLM+ methods used by the Environment Agency for fluvial and coastal systems. A discrete scenario-based approach has the advantage of reducing the complexity of the risk calculation and corresponds more closely to the type of modelling typically carried out to support local flood risk studies where a model may be run for a range of loading conditions (usually expressed as storm events of specified annual probability).

Figure 4.11 shows how, with values of a FRI calculated for three different annual probability events, the area under the curve can be determined using the trapezium rule (dashed line) to give the annual average FRI value. Figure 4.11 assumes that the onset of flooding is the 50 per cent annual probability event, and that the damages do not increase beyond those incurred for the 0.1 per cent annual probability for even rarer events. These assumptions may need to be reconsidered on a case-by-case basis.
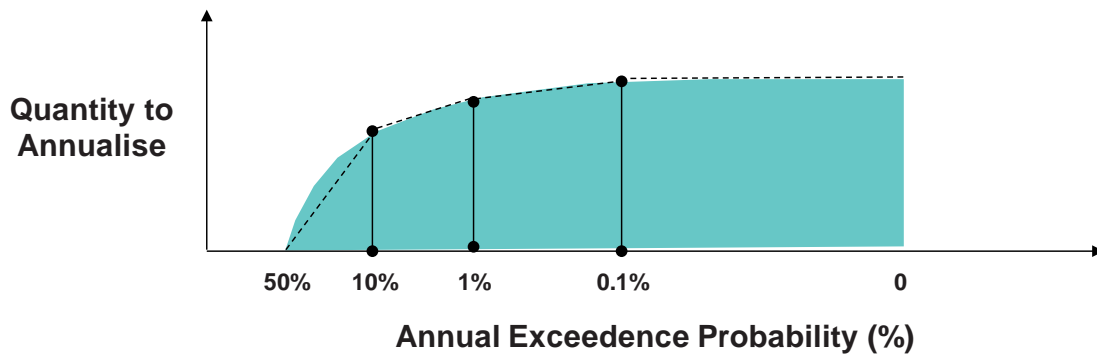
Figure 4.11 Approximation of annual average risk based on a limited number of system simulations. The vertical axis is a flood risk indicator (such as number of properties flooded, economic damages and so on). The annual probability refers to the probability weight attached to the system simulation used to calculate the FRIs.

4.5 Methods for a few users

The methods described in Sections 4.3 and 4.4 do not include fully probabilistic treatment of the above- and below-ground drainage systems. The aim of this section is therefore to describe a level of analysis that incorporates detail in both the probabilistic analysis of the system and the hydraulic modelling.

For the reasons discussed below, we can only present an outline design for a more sophisticated analysis than is currently practicable with operational risk modelling methods and tools. Figure 4.12 illustrates the inputs and outputs that are envisaged for such an approach should it become available.
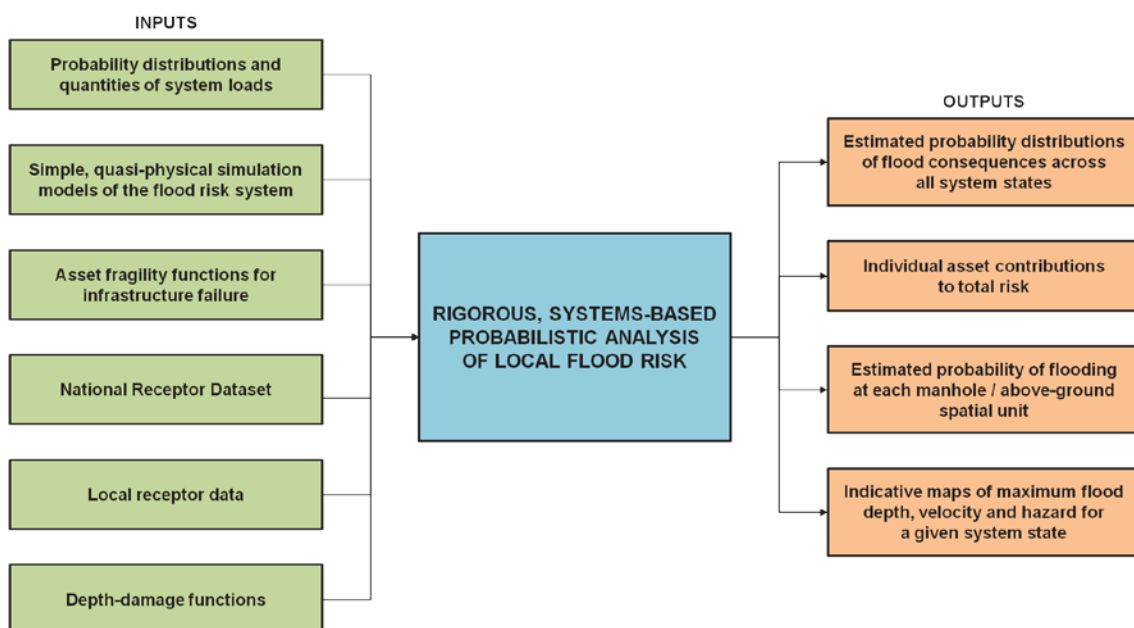
Figure 4.12 Key inputs and outputs of a probabilistic system performance method for local flood risk

A probabilistic system performance method for local flood risk (as envisaged here) implies two requirements:

1. Rigorous, structured sampling of the whole flood risk system (including the joint probability space of boundary conditions and system states).

2. Rigorous, spatially detailed modelling of flow pathways and hydraulic features of the system.

No methods or tools currently in *operational* use combine these two requirements. However, some *research* methods and tools can help to address aspects of both.

The DTI SAM project (HR Wallingford, 2009) addresses many aspects of the probabilistic treatment of boundary conditions and drainage system performance, particularly the below-ground system. However, our consultation with LLFAs during Phase 1 found that the DTI SAM tools were not in widespread use (or likely to be in the foreseeable future). It also seems too ambitious at the present time to expect LLFAs to use or specify these methods as a matter of course. This should not be read as a recommendation against use of the DTI SAM methods in general, rather a pragmatic reflection of the priorities and constraints facing LLFAs and other FCERM partners at this time. In fact, real progress was made in the DTI SAM research in understanding how to run a probabilistic analysis of above and below-ground systems.

A more fundamental issue may be achieving the level of process and spatial detail, particularly for above-ground flow routing, to match the detail captured by detailed hydraulic models used in local flood risk assessments. Here, an alternative may be to build on the approaches developed for river and coastal flooding in the Defra/Environment Agency FCERM project *Methods for Local Probabilistic Flood Risk Assessment*, which would extend the scenario-based approach taken here in Section 4.4 to include probabilistic analysis of important system components and/or states. For example, pragmatic methods for the probabilistic assessment of urban drainage system capacity, originally developed for use within the new Flood Map for Surface Water (see Defra/Environment Agency, 2010c), could be modified to reflect levels of system performance (degree of blockage/collapse) and/or maintenance. Whilst this type of approach would be fairly crude, it may be useful where the drainage system is poorly understood and/or sewer network models and data are unavailable. Finally, and perhaps most significantly, it may also help to introduce LLFAs to RASP-type concepts, such as fragility, within structured, probabilistic assessments of flood risk.

There is therefore a technical gap in current methods that requires further research and development to generate a useful probabilistic system performance method for local flood risk. It may be that this level of assessment is simply not cost effective or beyond the technical means of most LLFAs.

5 Prototype software for local flood risk assessment

5.1 Introduction

This project aimed to create software tools to demonstrate how the methods outlined in Section 4 can be implemented for operational purposes. These software tools are intended to be useable "proof of concepts" rather than operational, business-ready products. In Section 6, the tools are demonstrated using case study data for several hypothetical cases but, as prototypes, will not undergo formal testing and acceptance procedures as set out in Defra/Environment Agency (2007).

The prototype software tools will be developed and delivered as "add-ins" for ArcGIS 9.3 only. Certain depth map processing functionality within the software tools also requires the ArcGIS Spatial Analyst extension. Not all LLFA users will have access to ArcGIS (see Defra/Environment Agency, 2010d) and any subsequent "roll out" will need to take this into account.

The prototypes are supplied with "quick start" user guidance that provides an overview of the software's capabilities and how to install the software. This guidance is provided in a separate report (*SC070059 - Framework & Tools for LFRA - Software User Guide - Final.pdf*).

5.2 Basic requirements

The software tools described below have been developed according to a number of basic design requirements that emerged from the Phase 1 consultation with LLFA-led FCERM partnerships. According to these users, the software tools should be:

- **Simple to use**. Recognising the different levels of technical capacity across LLFAs, the software should be developed with clear, simple and intuitive interfaces and include "tool tip" help messages wherever possible.

- **Efficient to use**. LLFAs have limited resources for investigating and alleviating local flood risk issues that should not be absorbed by onerous and/or esoteric risk assessment tools.

- **Compatible with widely available datasets, modelling approaches and software**. In many situations, the inputs to the software tools will be "default" flood risk datasets covering England and Wales provided by the Environment Agency, but LLFAs must be able to make use of any hydraulic system models and improved receptor data held locally. Therefore, the software tools should not make any assumptions regarding the structure and format of the input data.

- **Highly visual and GIS-based**. The software tools should help to communicate flood risk to non-technical decision-makers, partners and groups. They should also be able to provide spatial summaries that are easy to share with, and be interpreted by, local authority colleagues (for example for emergency and spatial planning purposes).

5.3   Software tools

In terms of software, this project has produced two tools:

1. A **Calculator** for deriving flood risk indicator and undertaking property-level depth-damage analysis.

2. A **Viewer** for efficient interrogation and presentation of the calculator outputs.

These two tools can be used to implement the risk assessment methods set out in Section 4. The structure and work flow of the software created is shown in Figure 5.1.

It is necessary to calculate and analyse the flood risk indicators and depth-damage results using separate software tools as these can be time-consuming to compute, particularly for large, geometrically complex datasets such as national flood maps or very high resolution raster depth maps. Performing these calculations together within a single software tool is therefore not practicable for large areas and/or very detailed inputs.
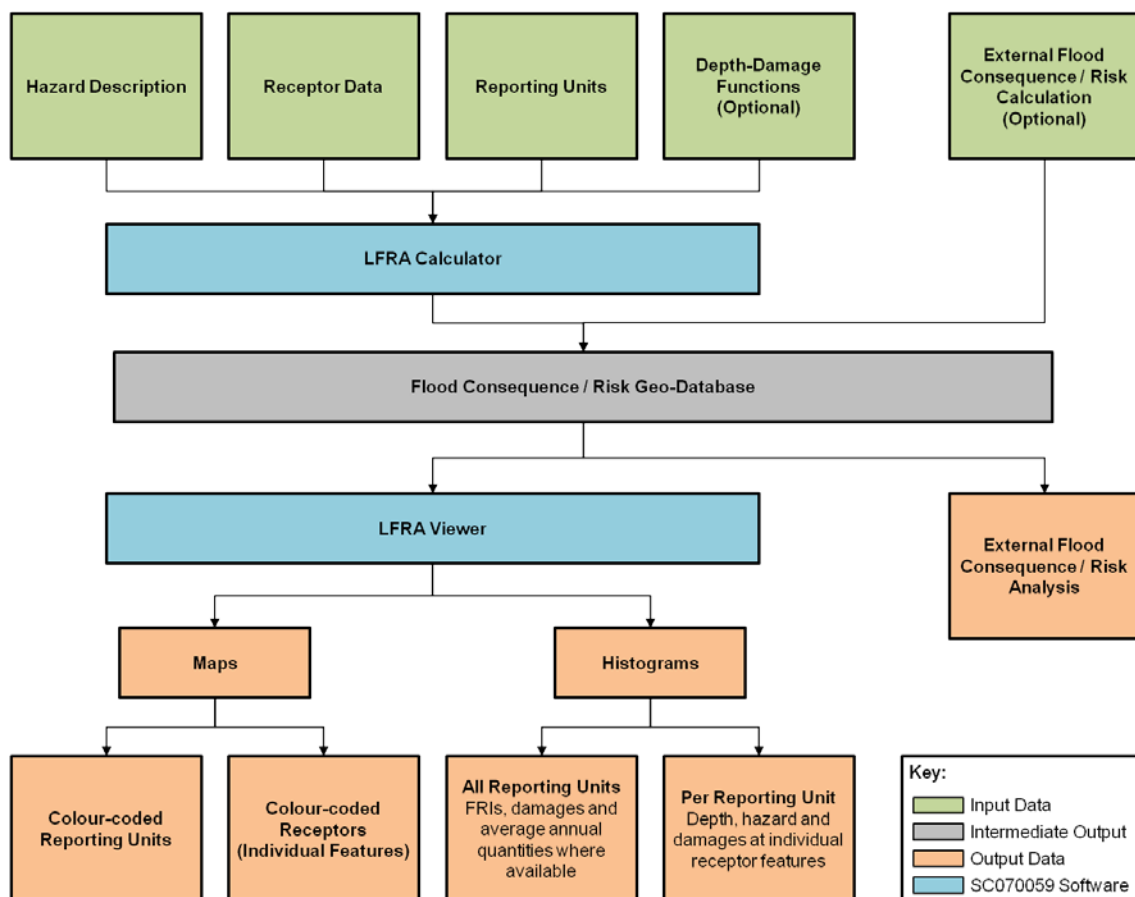

Figure 5.1 Structure and work flow of prototype software tools

5.4   LFRA Calculator

The Local Flood Risk Assessment (LFRA) calculator tool provides a functional implementation of the methods described in Sections 4.3.1-4.3.4 and 4.4.1-4.4.4. Therefore it can:

- spatially query flood extent outlines against receptor data to determine counts, lengths and areas of affected receptors within a set of reporting units;

- attribute representative depth and hazard information to individual properties and assets and calculate economic damages where suitable functions exist or have been defined by the user;

- evaluate annual average quantities of FRIs and damages where multiple, probability-weighted scenarios are available.

The calculator tool also offers LLFAs total flexibility to apply this tool to whatever flood risk information has been agreed by local partners and report the outputs on locally chosen spatial units. Required inputs, which can be supplied in any ArcGIS-supported format, consist of:

- a description of the hazard, provided by national flood maps from the Environment Agency or locally-available modelling;

- point, polyline or polygon receptor data provided, for example, by locally-validated/augmented subsets of the National Receptor Dataset;

- a set of reporting unit polygons (such as regular grids or irregular catchments/administrative units) that are subsequently attributed with the flood risk indicators calculated for each unit;

- Multi-Coloured Manual (MCM) or user-defined depth-damage functions (optional unless depth information is provided and damage estimates are required).

The software makes no assumptions on the structure and format of the input data.

As such, the calculator tool, even in prototype form, provides a powerful, flexible means of implementing the risk assessment methods outlined in the previous sections. However, the software has no knowledge of, or means of capturing, the quality of the input data or modelling approaches/data collection strategies used to derive it. Therefore, the adage "garbage in, garbage out" is appropriate here.

To assist with data management and provide transparency in the risk assessment process, text-based "settings" and geo-processing log files are written out for each run of the calculator tool. The settings file can also be used to "hot start" the calculator using previous data and parameter choices.

5.5   Flood consequence/risk geo-database

The calculator tool produces an ArcGIS-compatible geo-database that contains FRI-attributed reporting units and, if calculated, depth/hazard-attributed receptor data.

In most cases, it is envisaged that the geo-database will be read directly in the viewer software, but it has been structured such that it is straightforward to extract data for use in third party software (such as detailed benefit-cost or receptor vulnerability analysis, existing spatial/emergency planning systems). Similarly, flood consequences and risk

information calculated outside of the calculator but on a consistent set of reporting units can be imported into an existing geo-database.

5.6 LFRA Viewer

The viewer tool provides an efficient means of visualising, interrogating and presenting the flood consequence/risk information contained in the geo-database and does not make any assumptions regarding the inputs and outputs from the calculator tool. In terms of functionality, it can:

- provide maps, charts and summary tables of the flood risk indicator and property-level depth-damage analysis;

- visualise depth, hazard and damages at individual receptors (if calculated);

- allow users to set thresholds and classify consequence/risk on a FRI-by-FRI basis (see Section 4.3.5);

- objectively identify flood risk hotspots using the "single threshold" or "dual threshold" approaches (see Section 4.3.5);

- prioritise identified hotspots using the simple priority scoring system described in Section 0;

- help to visualise changes in consequence/risk between selected flooding scenarios.

As for the calculator tool, session settings can be saved to a text-based log file that can allow users to return to and/or modify a previous analysis.

Outputs from the viewer software are used to illustrate the applied examples shown in the next section.

6 Example applications

6.1 Introduction

In this section, the methods and prototype software tools developed in Sections 4 and 5 are applied to data from Torbay and Gloucestershire LLFAs for two hypothetical cases:

1. Broad-scale screening of a range of flood consequences across a broad geographical area.

2. Detailed risk calculation to support benefit-cost analysis of potential flood mitigation options.

Here, we focus primarily on risk assessment activities likely to be undertaken as part of Level 1 or Level 2 SFRA, local flood risk management strategy and SWMP studies (see Figure 2.1) as these cover a range of requirements, spatial scales, levels of detail, and model and data availability. Through these examples, the aim is to demonstrate the fitness for purpose of the generic methods and supporting software for practical applications, not necessarily best practice implementation.

As shown in Section 7, there are a wide range of additional functions where our developments may be relevant. Although the methods and prototype tools have not been tested directly for these applications, they should be considered when drawing conclusions from the case study testing.

6.2 Available data

Data for developing, testing and demonstrating the case studies were kindly provided by Gloucestershire County Council and Severn Trent Water from their First Edition SWMP and Torbay Council from their Level 2 SFRA study. These data were received and processed as part of Phase 2 (see Section 5.2 of Defra/Environment Agency (2010b) for a full discussion) and comprise:

Gloucestershire

- County-wide information on previous flood incidents (approximately 500 records).

- Thirty-four surface water flood risk hotspots identified through manual analysis of historic flood records and Environment Agency Flood Map and AStSWF data.

- Simulation models that range in complexity from simple "direct rainfall" models to detailed, fully-integrated models of the above- and below-ground drainage systems. Each model provides at least a map of maximum flood depth and hazard for the 0.5 per cent annual probability rainfall event, while an integrated urban drainage (IUD) model of central Gloucester has been used to simulate a number of flood and mitigation scenarios for detailed assessment purposes.

Torbay

- Detailed reports describing the causative mechanisms and impacts of six historic flood incidents.

- A fully-integrated IUD model of Torquay capable of simulating flood depths and hazard for a range of probabilities (20, 10, 5, 3.33, 2, 1 and 0.5 per cent annual probability events).

For the same areas, the Environment Agency has also provided extracts from national flood risk datasets, including the flood maps for fluvial, coastal and surface water, the National Receptor Dataset and all historic flood records held in a variety of formats and systems.

6.3 Case 1: Broad-scale screening of flood risk

An important first step for many LLFAs and their FRM partners will be to understand the distribution of flood risk across their respective administrative areas and identify and prioritise locations requiring further, more detailed investigation. The outputs from such a screening exercise can inform a wide range of flood risk-related studies and strategic planning activities (such as emergency planning, local resilience, capital investment and asset management).

Here, we apply flood risk indicator-based approaches to national flood map and receptor datasets and assess a broad range of flood impacts across Torbay and Gloucestershire. Calculated FRIs are classified to automatically identify "indicative" flood risk hotspots which are then ranked based on user-defined priority scores for further detailed investigation. Higher-priority hotspots are compared against recorded flood incidents to test the robustness of the approach.

6.3.1 Torbay

The data inputs and parameter choices for the LFRA Calculator and viewer software are shown in Table 6.1 and Table 6.2 respectively.

Table 6.1 LFRA Calculator data inputs for Case 1 - Torbay

	Data	Source
Hazard Description	• Flood Map for Surface Water 0.5% annual probability ("deeper" band) • Flood Map Flood Zone 3	Environment Agency flood map outlines
Receptor Data	• Residential property points • Non-residential property points • Critical services points • Road and railway polylines • Agricultural Land Classification polygons (Grades 1-3 only)	Environment Agency National Receptor Dataset version 1.1
Reporting Units	540 500-m regular grid squares	User-defined .shp file
Depth-Damage Functions	N/A	
Additional Parameters	Five-metre horizontal resolution building footprint dataset to use detailed property count method (see Environment Agency, 2010e). Building buffer distance set to zero m.	Building footprint dataset back-calculated with- and without building digital terrain models (DTMs) used to produce the FMfSW. Note that this dataset is not presently available to LLFAs.
Disclaimer: Note that the data, property count methodology and parameter choices selected here are intended to demonstrate the functionality of the prototype software tools and may not reflect the best available locally agreed information/approach in practice.		

Table 6.2 LFRA Viewer parameter choices for Case 1 - Torbay

Flood Impact	FRI Name	Type	Lower Risk Threshold	Upper Risk Threshold	Relative Priority Score
Human Health	People	Count	50	200	10
	Critical Services	Count	1	3	5
Economic Activity	Non-Residential Properties	Count	25	100	5
	Roads & Railways	Length (m)	250	750	3
	Agricultural Land Classification (ALC) Grades 1-3	Area (ha)	0.5	1.5	1
Disclaimer: Note that the risk thresholds and relative priority scores shown here are arbitrary choices made by the Project Team to demonstrate the functionality of the prototype software tools. They do not reflect the views or FRM policies of Torbay LLFA.					

Summary maps for the five flood risk indicators calculated are shown in Figure 6.1. The classification thresholds used in each map are shown in Table 6.2.

As the maps are simply based on the spatial intersection of two well understood types of data (flood maps and receptors), the spatial distribution of flood impacts appears intuitively reasonable, even to non-technical partners. For example, it makes sense that more people are likely to be susceptible to flooding in more densely populated urban and peri-urban areas than in rural areas. It is also reasonable to assume that key physical catchment characteristics which affect the degree of susceptibility, such as river network density and local topography, are taken into account in the underlying flood modelling and mapping.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)
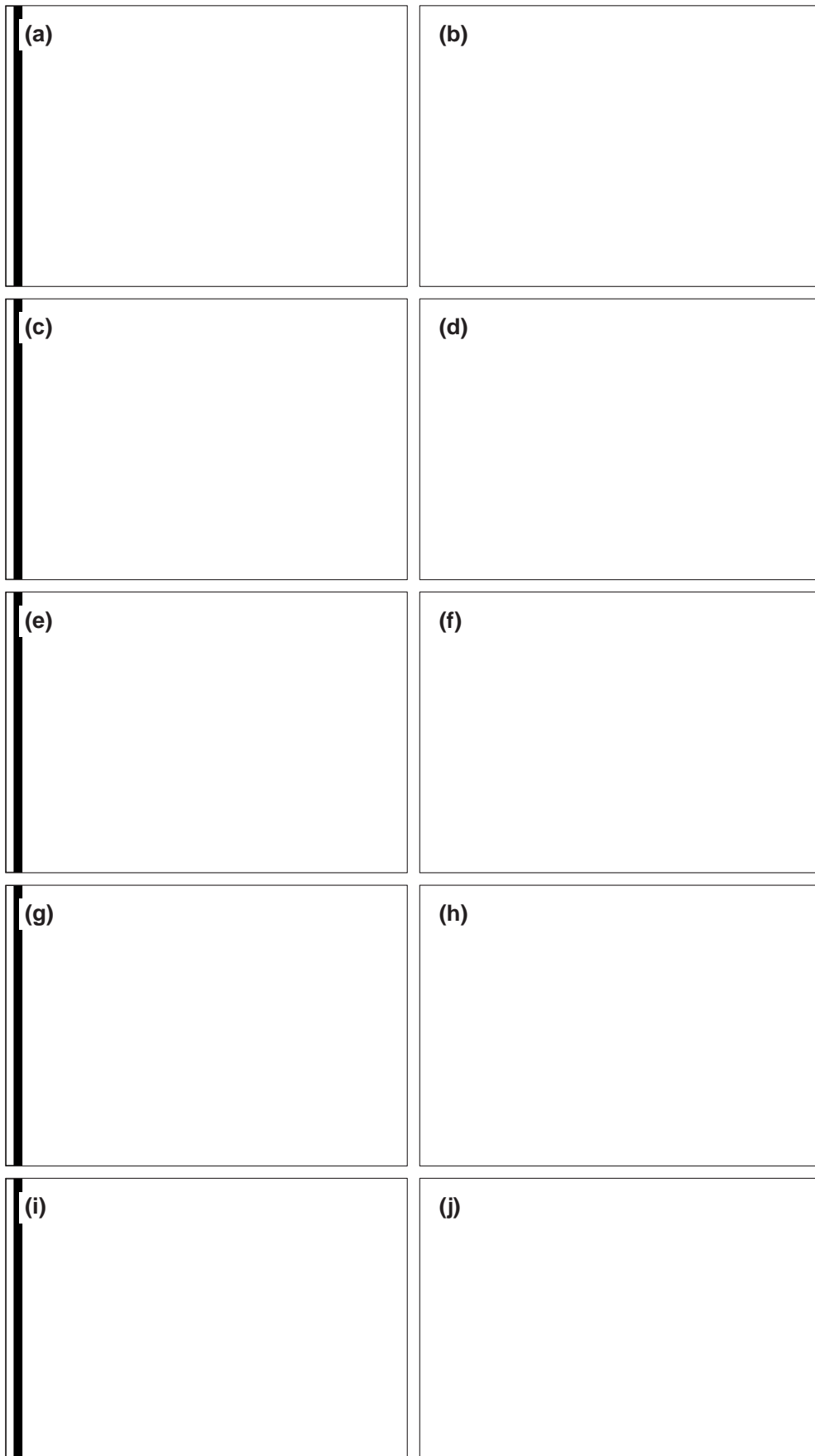
Figure 6.1 Classified flood risk indicator maps for Torbay LLFA. For each FRI (rows), sub-plots in the left and right columns are based on the Flood Map for Surface Water and Flood Map Flood Zone 3 respectively.

Framework and tools for local flood risk assessment - project report

Based on the simple "low – medium – high" classification applied to each indicator/ flood map, composite flood risk hotspots were produced using both the single and dual threshold approaches described in Section 4.3.5 (see Figure 6.2). These hotspots were also ranked using the priority scores shown in Table 6.2.
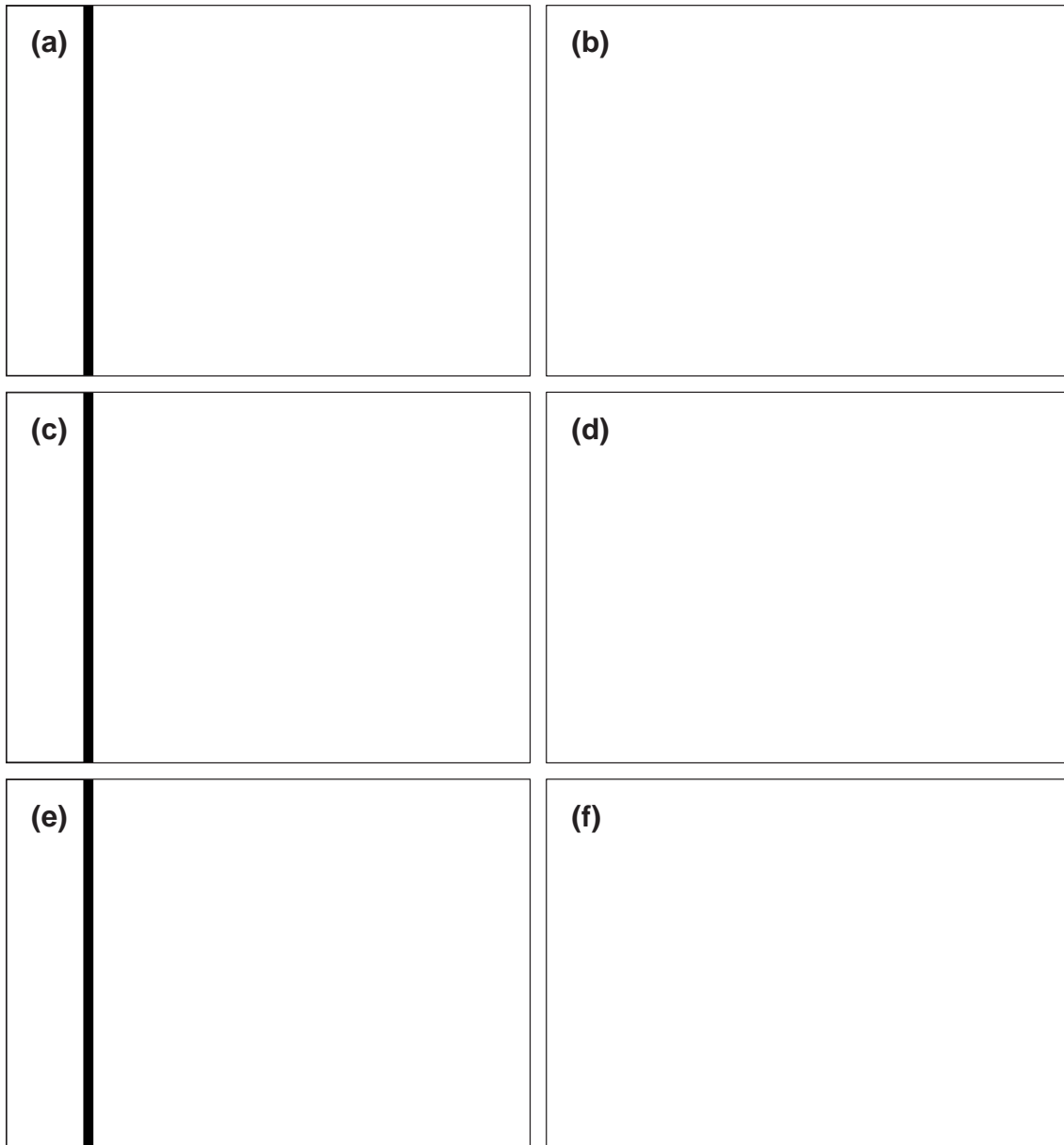
Figure 6.2 Composite flood risk hotspots for Torbay LLFA. For each hotspot identification method (columns), sub-plots show the effect of removing lower-priority hotspots from the total set and, in this case, the diminishing fit to the historical flood observations.

Figure 6.2 and Table 6.3 demonstrate the effects of different hotspot identification methods and of removing lower-priority hotspots from the total set. As shown in Section 0, more hotspots are identified using the dual threshold approach, which is reasonable as the method also considers information in the "medium" risk category (between the upper and lower thresholds) in the hotspot analysis.

In this particular case, removing hotspots based on their overall priority score reduces their fit to the historical flood observations. This will not be the case everywhere and it is important that the distribution of hotspots is checked against information on past floods wherever possible.

Table 6.3 Number of flood risk hotspots identified for Torbay LLFA

	Single Threshold Approach		Dual Threshold Approach	
	Total Number	Percentage of Reporting Units	Total Number	Percentage of Reporting Units
All	60	11	74	14
Overall Priority Score greater than or equal to 10	44	8	44	8
Overall Priority Score greater than 10	12	2	32	6

6.3.2   Gloucestershire

A similar broad-scale analysis of flood risk is presented for Gloucestershire LLFA, albeit with a different description of the surface water flood hazard and choice of reporting units to demonstrate the flexibility of the prototype software tools. The data inputs and parameter choices are shown in Table 6.4 and Table 6.5 respectively.

Table 6.4 LFRA Calculator data inputs for Case 1 - Gloucestershire

	Data	Source
Hazard Description	• Areas Susceptible to Surface Water Flooding ("intermediate" susceptibility band) • Flood Map Flood Zone 3	Environment Agency flood map outlines
Receptor Data	• Residential property points • Non-residential property points • Critical services points • Road and railway polylines • Agricultural Land Classification polygons (Grades 1-3 only)	Environment Agency National Receptor Dataset version 1.1
Reporting Units	142 irregular council wards	Extracted from Ordnance Survey Open Data Boundary-Line product
Depth-Damage Functions	N/A	
Additional Parameters	N/A	
Disclaimer: Note that the data, property count methodology and parameter choices selected here are intended to demonstrate the functionality of the prototype software tools and may not reflect the best available locally agreed information/approach in practice.		

Table 6.5 LFRA Viewer parameter choices for Case 1 - Gloucestershire

Flood Impact	FRI Name	Type	Lower Risk Threshold	Upper Risk Threshold	Relative Priority Score
Human Health	People	Count	100	500	10
	Critical Services	Count	1	3	6
Economic Activity	Non-Residential Properties	Count	10	50	2
	Roads & Railways	Length (m)	2,500	7,500	6
	ALC Grades 1-3	Area (ha)	100	300	4
Disclaimer: Note that the risk thresholds and relative priority scores shown here are arbitrary choices made by the Project Team to demonstrate the functionality of the prototype software tools. They do not reflect the views or FRM policies of Gloucestershire LLFA.					

Summary maps for the five flood risk indicators calculated are shown in Figure 6.3. The classification thresholds used in each map are shown in Table 6.5.

The effect of using irregular council wards as reporting units, rather than a high resolution regular grid, can clearly be seen in Figure 6.3. Use of council wards may be useful for administrative purposes but they will inevitably reduce the precision of the indicator mapping, particularly across larger wards in more rural areas. The LFRA Calculator outputs cannot be disaggregated below the level of the reporting unit to prevent over-interpretation of uncertain polygon flood map data (at the property level).

Perception issues arise when using irregular spatial units in thematic maps, such as those in Figure 6.3. Wards in more densely populated urban areas tend to be smaller than rural and peri-urban counterparts and may be "overlooked" in favour of larger, more-easily distinguished reporting units. This may hinder the usefulness of such maps for communicating flood risk, particularly to non-technical decision-makers such as councillors who represent and are accountable for flooding in their areas. It is therefore important to use the charts and summary tables of absolute indicator values in conjunction with the maps to get a complete understanding of the flood risk distribution.

As for Torbay, composite flood risk hotspots were produced and ranked using the thresholds and priority scores shown in Table 6.5.

Table 6.6 and Figure 6.4 demonstrate the effects of different hotspot identification methods and of removing lower-priority hotspots from the total set. It is clear from Figure 6.4 that many of the highest priority hotspots lie within or adjacent to the extensive River Severn floodplain. The River Severn is designated as a Main River and thus only of direct interest to Gloucestershire LLFA where it interacts with local flood risk sources (see Section 2.3.1). This example shows that Environment Agency fluvial and coastal Flood Map data should be used with caution in the application of these semi-automated methods.

Also apparent from Figure 6.4 is the (im)precision of irregular ward-based mapping compared to point-based recorded flood incidents and locally-determined priority SWMP locations. This mismatch in spatial scales may be significant if users wish to calibrate the underlying risk classification thresholds against localised, historic flood data.

Table 6.6 Number of flood risk hotspots identified for Gloucestershire LLFA

	Single Threshold Approach		Dual Threshold Approach	
	Total Number	Percentage of Reporting Units	Total Number	Percentage of Reporting Units
All	47	33	94	66
Overall Priority Score greater than or equal to 15	11	8	26	18
Overall Priority Score greater than or equal to 20	4	3	11	8

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)
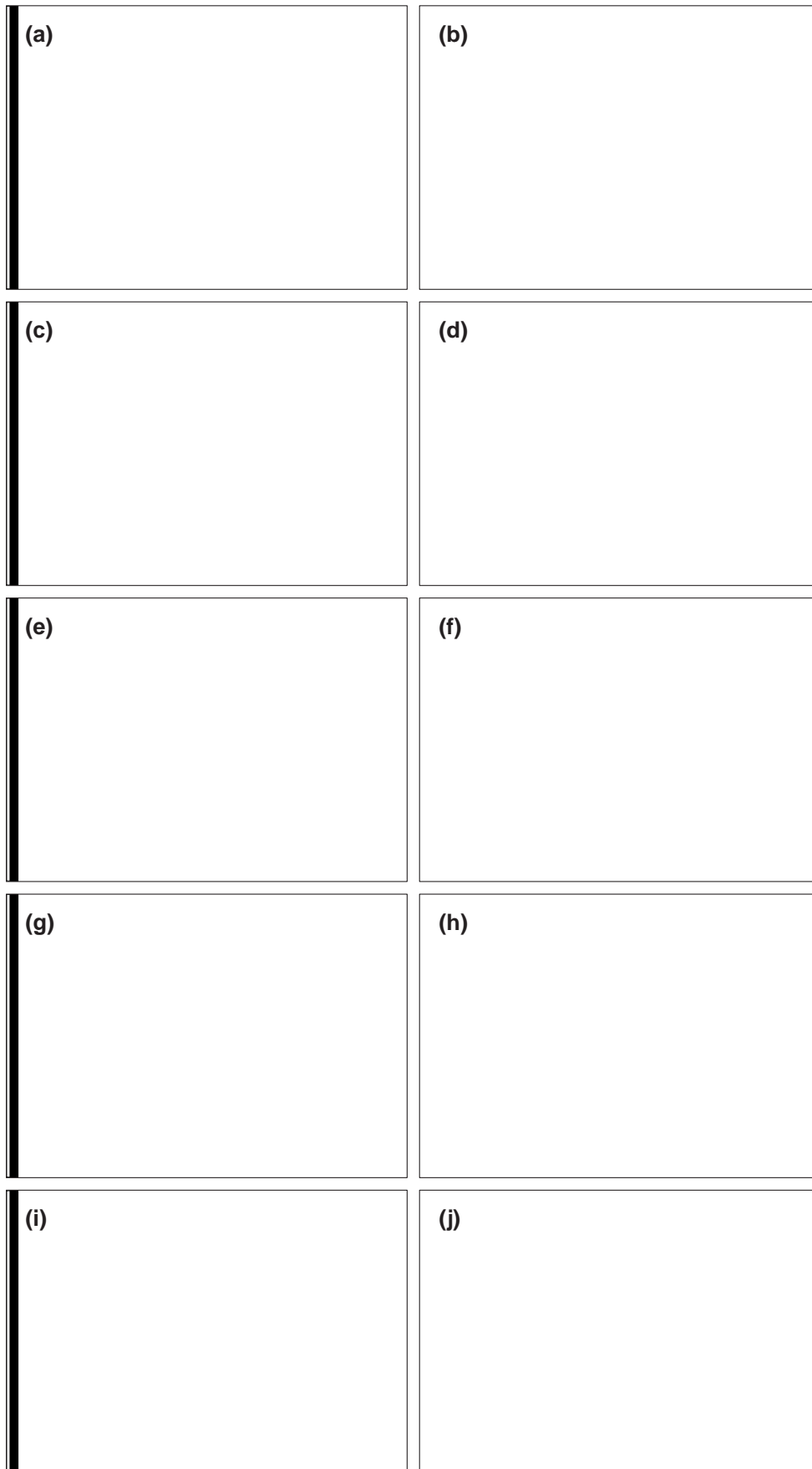
Figure 6.3 Classified flood risk indicator maps for Gloucestershire LLFA. For each FRI (rows), sub-plots in the left and right columns are based on the Areas Susceptible to Surface Water Flooding mapping and Flood Zone 3 respectively.
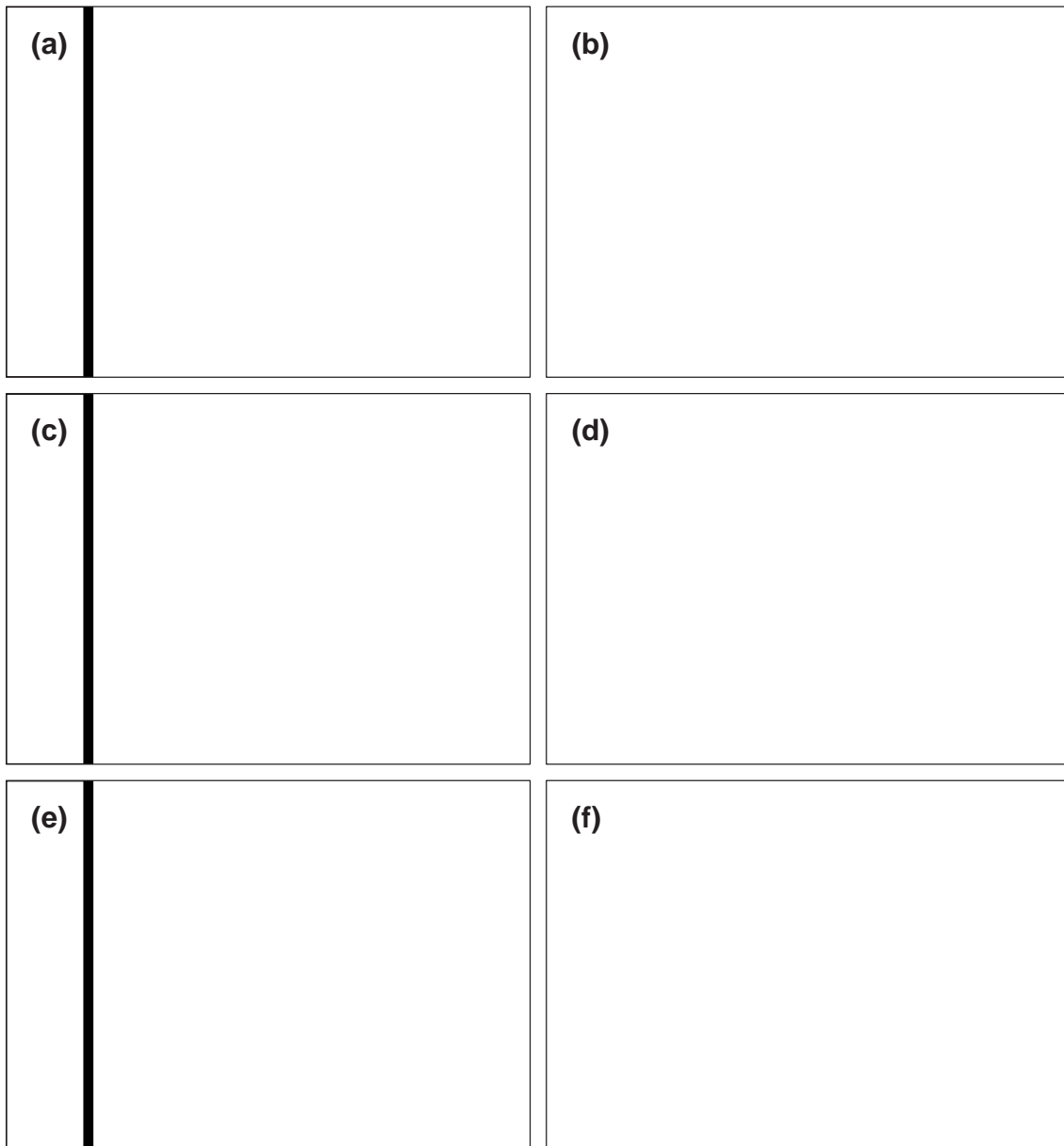
Figure 6.4 Composite flood risk hotspots for Gloucestershire LLFA. For each hotspot identification method (columns), sub-plots show the effect of removing lower-priority hotspots from the total set and the fit to available historical flood observations and locally-determined priority SWMP locations.

6.3.3 Summary of lessons learned

The following bullet points provide a summary of the lessons learned from Sections 6.3.1 and 6.3.2:

- The methods and prototype software tools developed in Sections 4.3 and 5 have been applied very successfully and efficiently (approximately 1.5 hours calculation time on a standard desktop PC in each case) to national flood risk data sets provided by the Environment Agency covering Torbay and Gloucestershire LLFA areas.

- The prototype software tools provide LLFAs with the desired flexibility to assess flood risk using locally agreed surface water information (including AStSWF mapping and FMfSW data) and risk classification thresholds.

- LLFAs have total flexibility regarding how to define and prioritise flood risk hotspots based on their chosen flood risk indicators.

- Depending on the number of FRIs calculated, the risk classification thresholds selected, and the size of the study area and reporting units, it is easily possible to define large numbers of hotspots that can be difficult to differentiate from each other. Priority scoring provides an effective means of reducing the total number of hotspots to a more manageable number but users should carefully consider which FRIs are used in the analysis and the relative priority score each is assigned. These decisions are highly subjective and should be clearly recorded, along with their justification, as part of the evidence base.

- The semi-automated nature of the screening approach means that local validation of the input data is essential, particularly the National Receptor Dataset.

- Data in the current version of the NRD contains significant gaps with respect to critical services, and designated environmental sites and heritage assets. However, the NRD is the subject of an ongoing improvement programme so this situation is likely to improve in the near future.

- Irregular reporting units should be used with caution, particularly where there is large variation in the size of units across the study area.

- There is no Environment Agency flood map product that describes flooding along all ordinary watercourses (only larger ordinary watercourses, where the catchment is greater than 3 km^2, are included in the Flood Map). The Flood Map data can therefore be used with caution, but users should be aware that it primarily identifies areas at risk from fluvial main river and coastal flooding.

6.4 Case 2: Detailed risk calculation to support benefit-cost analysis of flood mitigation options

More detailed risk assessments can be undertaken in areas identified as hotspots for local flood risk. These areas can be identified from the outputs of analyses similar to that described above, existing flood risk assessments, or where there are already known flooding problems. The purpose of more detailed assessments is to gain a better understanding of the causes and consequences of flooding, and to test the benefits of potential mitigation measures. Typically this is achieved through local modelling of surface and/or sub-surface drainage systems.

The two examples given below illustrate how the methods and prototype software tools can help LLFAs to understand the impacts of flooding at the scale of individual receptors based on the outputs from locally-available hydraulic models. In each case, the availability of depth information allows economic damages to be calculated and analysed at much finer spatial scales than those supported by the national flood map datasets provided by the Environment Agency.

6.4.1   Torbay

The data inputs and parameter choices for the LFRA calculator and viewer software are shown in Table 6.7.

Table 6.7 LFRA Calculator inputs for Case 2 - Torbay

	Data	Source
Hazard Description	One-metre horizontal resolution raster depth maps from a detailed integrated urban drainage model for the 20, 10, 5, 3.33, 2, 1 and 0.5 per cent annual probability events	InfoWorks CS model developed by Torbay LLFA to support their Level 2 SFRA study
Receptor Data	"All" property points layer comprising residential and non-residential properties	Environment Agency National Receptor Dataset version 1.1
Reporting Units	40 100-m regular grid squares	Default option within LFRA Calculator
Depth-Damage Functions	Multi-Coloured Manual 2010 residential and non-residential curves	Environment Agency/Flood Hazard Research Centre, Middlesex University
Additional Parameters	*Flood Datasets* form • Flood depth descriptor: Mean • Zero damages: 50 per cent annual probability • Wet/dry depth threshold: 0.01 m • Buildings modelled as voids: True • Building buffer distance: 2 m *Calculate Property Damages?* form • Property threshold: 0.25 m • Default floor area: 50 m^2	• Building footprint data set extracted from Ordnance Survey MasterMap Topography Layer and checked against simulation boundary polygon • Remaining parameter choices made arbitrarily by Project Team to demonstrate the functionality of the prototype software tools

A sample of outputs from the LFRA Viewer tool is provided in Figure 6.5. Within the viewer software, users can interrogate depth, hazard and damage information at individual receptors and set classification thresholds to ease the interpretation and/or validation of potentially complex datasets. Step-by-step instructions for these functions are provided in Section 5.4.1 of the software user guide (*SC070059 - Framework & Tools for LFRA - Software User Guide - Final.pdf*).

Depth, hazard and damage information can also be extracted at the reporting unit/receptor scales from the flood risk geo-database (see Section 5.5) to be used within other locally-available software systems (such as for detailed benefit-cost or receptor vulnerability analysis, existing spatial/emergency planning systems).
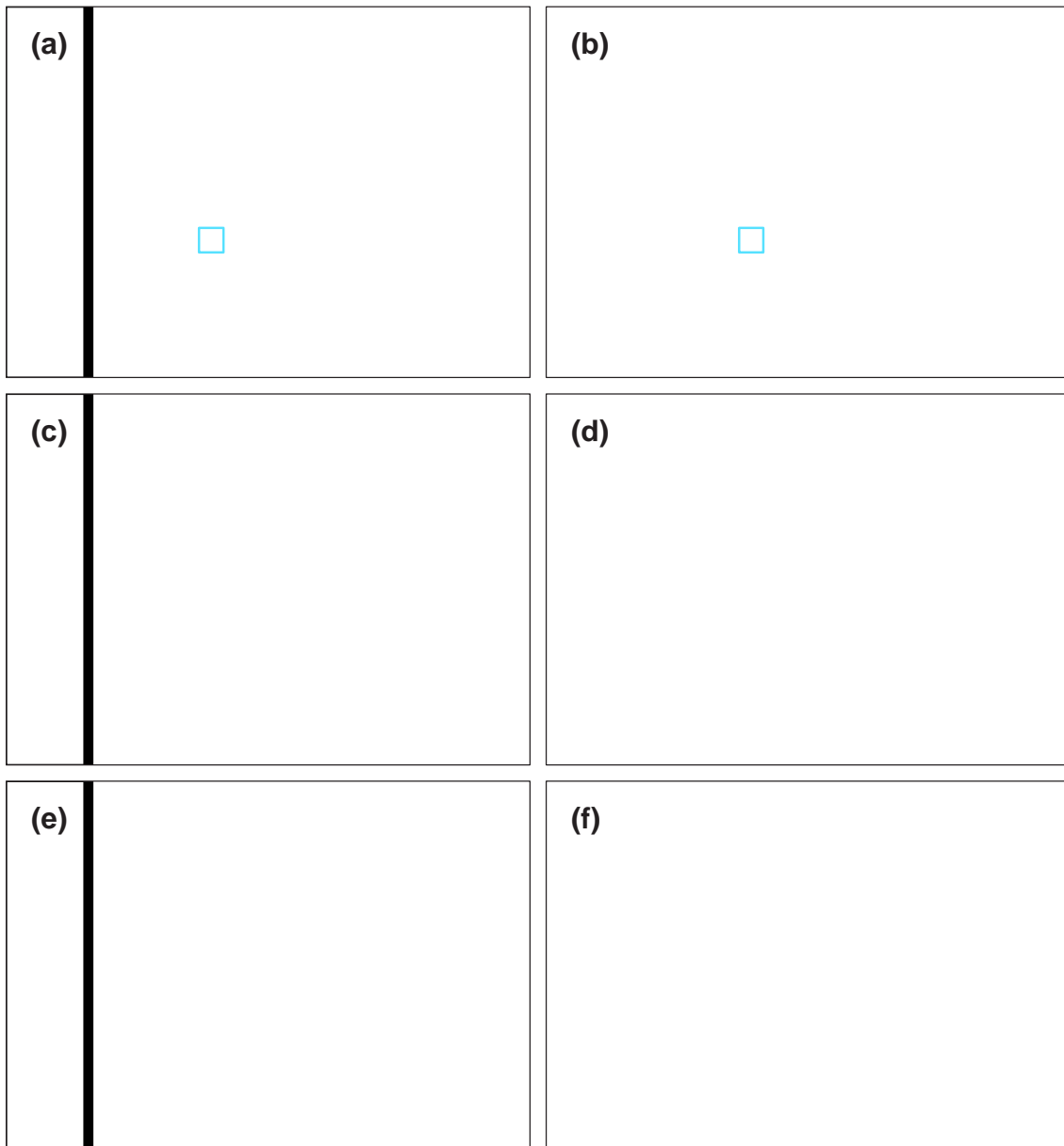
Figure 6.5 Depth and damage mapping based on the results from a fully-integrated IUD model of Torquay. For the 10 and one per cent annual probabilities of flooding (left and right columns respectively), sub-plots (a) and (b) map economic damages across regular grid-based reporting units of 100-m horizontal resolution. For the selected grid square (shown with a thick blue border), sub-plots (c) and (d) map the depth of flooding at individual receptors, while sub-plots (e) and (f) show the corresponding damage estimates.

6.4.2   Gloucestershire

In the second example, we use "before" and "after" scenarios developed within a detailed IUD model of central Gloucester to evaluate the total reduction in annual average damages associated with a number of proposed improvement measures, such as sewer improvements, defence walls, defence embankments, improving entrances to existing culverts, construction of new culverts, improvements to existing storage areas, creation of new storage areas and other small miscellaneous channel improvements (Gloucestershire County Council, 2010).

The data inputs and parameter choices for the LFRA Calculator and viewer software are shown in Table 6.8.

Table 6.8 LFRA Calculator inputs for Case 2 - Gloucestershire

	Data	Source
Hazard Description	"Before" and "after" two-metre horizontal resolution raster depth maps from a detailed integrated urban drainage model for the 50, 20, 10, 4, 2, 1.33, 1, 0.5 and 0.1 per cent annual probability events	InfoWorks CS model developed by Richard Allitt Associates on behalf of Gloucestershire LLFA to support their First Edition SWMP study
Receptor Data	"All" property points layer comprising residential and non-residential properties	Environment Agency National Receptor Dataset version 1.1
Reporting Units	235 100-m regular grid squares	Default option within LFRA Calculator
Depth-Damage Functions	Multi-Coloured Manual 2010 residential and non-residential curves	Environment Agency/Flood Hazard Research Centre, Middlesex University
Additional Parameters	*Flood Datasets* form • Flood depth descriptor: Mean • Zero damages: 100 per cent annual probability • Wet/dry depth threshold: 0.01 m • Buildings modelled as voids: True • Building buffer distance: 2 m *Calculate Property Damages?* form • Property threshold: 0.25 m • Default floor area: 50 m^2	• Building footprint data set supplied with the IUD model by Gloucestershire LLFA • Remaining parameter choices made arbitrarily by Project Team to demonstrate the functionality of the prototype software tools

Total counts of affected properties and corresponding damage estimates for each flood probability are shown in Table 6.9. These data can be annualised automatically within the LFRA Calculator and mapped spatially using the LFRA Viewer (see Figure 6.6).

Table 6.9 Summary of "before" and "after" property counts and damage estimates associated with a combination of improvement options for surface water management in central Gloucester

Event Probability (%)	Existing Scenario		Improved Scenario	
	Count of Affected Properties	Damages (£M)	Count of Affected Properties	Damages (£M)
100	0 (assumed)	0 (assumed)	0 (assumed)	0 (assumed)
50	810	1.28	673	1.14
20	1,103	1.52	933	1.43
10	1,783	2.54	1,354	2.15
4	2,665	4.32	2,172	3.27
2	3,704	6.81	2,995	4.27
1.33	4,401	9.09	3,783	5.31
1	4,994	11.28	4,394	6.69
0.5	6,732	18.35	6,348	9.84
0.1	9,749	41.79	9,450	19.05

Framework and tools for local flood risk assessment - project report

(a)

(b)

(c)

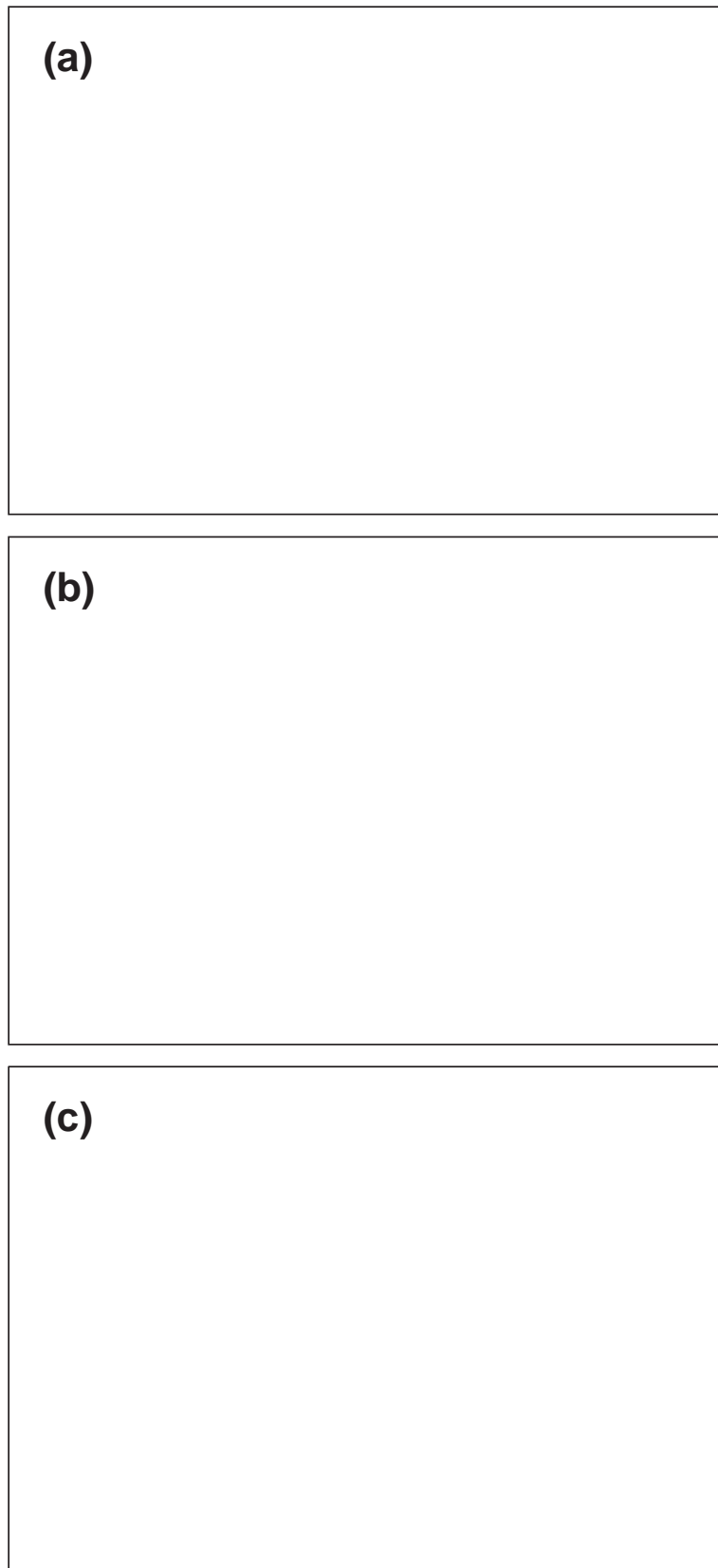**Figure 6.6 "Before" (a) and "after" (b) annual average damages associated with a combination of improvement options for surface water management in central Gloucester. Sub-plot (c) shows the difference between (a) and (b). The difference was calculated by subtracting the "before" from the "after" so that map values are negative where the damage has decreased and positive where the damage has increased.**

Despite the overall reduction in the number of affected properties and associated damages "after" flood mitigation measures have been assessed (shown in Table 6.9), Figure 6.6c shows that the proposed scheme will actually increase annual average damages (AAD) in some areas. In fact, analysis of the underlying data shows that, while AAD estimates have decreased in 108 reporting unit squares, they have increased in 77 such squares. However, this result should not be over-interpreted as there are important differences in the property data set and depth-damage relations used in this case study example and the Gloucestershire First Edition SWMP.

Mapping of AAD residuals may therefore provide a useful basis for optimising capital scheme designs (and other flood risk management measures where detailed hydraulic modelling is likely to be a prerequisite) in the future. A similar but more sophisticated approach has been used previously in the drainage system optimisation tools within DTI SAM (HR Wallingford, 2009).

6.4.3   Summary of lessons learned

The following bullet points provide a summary of the lessons learned from Sections 6.4.1 and 6.4.2:

- The methods and prototype software tools developed in Sections 4.4 and 5 were applied successfully and efficiently to the outputs from detailed IUD models provided by Torbay and Gloucestershire LLFAs.

- The prototype software tools provide LLFAs with an efficient means of understanding potentially complex economic damage information at the reporting unit and/or individual receptor scales. Depth and hazard data can also be interrogated on a receptor-by-receptor basis.

- Economic damage information can be used to quantity flood risk and inform investment decisions.

- Annual average quantities, such as damages, can be derived as single summary statistics or mapped across reporting units. These maps may provide a simple, objective basis for optimising the effectiveness of capital scheme in the future.

- With or without the prototype software tools, a lot of effort is typically expended in calibrating and validating hydraulic models to produce an accurate description of the flood hazard. However, to produce economic damage information, key attributes of the property data set, such as MCM code, floor area, floor level code and property threshold level, must also be correct. Default information is provided in NRD Property Point dataset but this is likely to require a thorough review/update by local users.

7   Wider utility of project outputs

As noted in the previous section, a wide range of potential users within the FCERM community could benefit from our developments. The utility of our outputs are summarised in Table 7.1 below.

Table 7.1 Wider utility of project outputs

Flood and Water Management Act 2010	Flood Risk Regulations 2009
• Support the development and implementation of local flood risk management strategies • Enable efficient partnership working, within and across administrative areas • Impact analysis of historic flood events where polygon extents are available • Identification of significant FCERM assets and infrastructure • Screen risk to (and potentially from) LLFA-owned or third party infrastructure, assets and features	• Flood Risk and Flood Hazard Mapping (Part 3) • Flood Risk Management Plans (Part 4)
Local Flood Risk Management Strategies	**Local Resilience Forums**
• Establish a consistent understanding of risk to form the basis of a local strategy • Testing the sensitivity of local thresholds for different levels of flood risk (e.g. "high", "medium" and "low") • Provide evidence base to objectively prioritise/justify local interventions and investment decisions	• Risk based pre-incident planning and incident management • Updating Multi-Agency Flood Plans and Community Risk Registers
Local Planning Authorities	**Non-Flood Related "Impact" Studies**
• Implementation of PPS 25/TAN 15 approaches (e.g. sequential test) • Taking account of receptor exposure in the planning/development control process for local development frameworks or individual planning applications	• Sensitivity to climate change (see case study examples in ongoing Environment Agency project *Climate Change Information for Local Flood Risk Management Strategies in England*) • Heatwaves • Biodiversity • Pollution incidents • Asset/infrastructure susceptibility to environmental risk

The value and timeliness of this project was also underlined at the Flood Risk Mapping and Damage Estimation Workshop hosted by WaPUG/CIWEM in July 2010 (proceedings published at www.ciwem.org). The workshop, attended by experts from across the UK water industry, **identified the need for a consistent flood risk and consequence analysis method as the key area for further work**. The lack of consistency, in terms of the methods, models and data applied, across the different organisations involved at a local or national level, was seen as a major barrier to efficient partnership working.

8 Implementation and further research requirements

8.1 Implementation

This project has created a suite of generic methods for local flood risk assessment that recognise the different levels of technical capacity and availability of local models and data across LLFAs. The methods are designed to be widely accessible, easy to follow and compatible with widely available datasets, modelling approaches and software. They can be implemented by anyone carrying out a risk assessment of surface water flooding and with access to, and basic familiarity with, GIS software.

The Flood and Water Management Act (2010) and the Flood Risk Regulations (2009), have been given LLFAs responsibility for the mapping, planning and management of local flood risk (including surface water). The Environment Agency has a strategic overview in England and strategic oversight role in Wales. Environment Agency functions include the strategic overview role for all sources of flooding and coastal erosion and supporting the development of tools and approaches to understand these risks. The development of the framework and methods supports key elements of the strategic overview and oversight roles, by providing evidence and advice to support others, as well as sharing knowledge and good ways of working.

The framework and method offers a consistent approach to risk assessments, whilst allowing local flexibility in the data used. This can support partnership working through better understanding and communication of flood risk. Although outside of the scope of this project, it is understood that a degree of consistency in data formats and data structures will help facilitate information sharing between partner organisations. LLFAs should consider this when working in partnership with others. The Environment Agency recommended standard data fields when working with partners to gather historic surface and groundwater flooding data. The Environment Agency is planning additional work with LLFAs and risk management authorities to establish standards, including flood event data collection advice. Flood and Water Management Act statutory guidance on 'Co-operation and requesting information in flood and coastal risk management' (Defra / Environment Agency, 2011) provides general advice on information sharing issues.

To demonstrate how the method can be applied prototype software tools have been developed as "proof of concept". These prototype tools will be made available to LLFAs with basic user guidance. There are no current plans for the Defra/Environment Agency joint FCERM R&D programme to develop the prototype tools into "business ready" desktop software. Further development of the prototype tools should be based on LLFA user needs, after a period of applying the framework and methods in their flood risk management work and testing of the prototype tools.

Section 8.1 outlines some of the issues to be considered if/when the prototype software tools are released to potential end users within LLFAs.

8.1.1   Roll-out of prototype software tools

Who could get them?

The software could potentially be used by anyone with access to ArcGIS 9.3 (and the Spatial Analyst extension). This could be users within the Environment Agency, local authorities, water companies, or any other professional partner/risk management authority.

It is recognised that, the prototypes will not work in MapInfo (or any other GIS software) and would need to be re-developed from scratch to work on this platform. The ArcGIS software would provide a useful "blueprint" but the geo-processing routines and raster handling are fundamentally different in the two software.

How will they be made available?

Access to the prototype software could be managed by the Environment Agency and a variety of mechanisms could be used, such as web distribution, incorporation into the GIS Edit Environment, or the software being made available on demand. Some of these potential mechanisms would require further investigation before they could be implemented.

Alternatively, delivery could be managed via partners, such as licensing to consultants for efficiency and to share costs and risks.

8.1.2   Managing, supporting and maintaining software tools

The software tools are designed to provide total flexibility on data inputs and thus offer a powerful, long-term solution for implementing the proposed risk assessment methods. However, it is inevitable that they will need maintaining and updating as the underlying ArcGIS software and business user requirements change in the future. The prototypes are produced in both executable and source code formats, so further development is feasible in theory.

In terms of software support, this could be managed by third parties. During discussions at various stages of the project, most potential end users felt that a web presence was key to providing up-to-date guidance and developing a strong "user community". For other software (such as TUFLOW), these communities have developed through forums and message boards that allow users to share best practice/tips and tricks. Particularly relevant here is the successful Flood Risk and Water Management Network (or FlowNet) discussion group, hosted by the Local Government Association, for sharing of ideas, good and innovative practice and challenges among local authority practitioners.

8.1.3   End user training

The software is designed to be simple, efficient and intuitive to use, and is supplied with "quick start" user guidance that provides an overview of the software's key functionality. Should more formal training be required, it is likely that a short demonstration, face-to-face or via a video-conferencing system, would be sufficient to meet most users' needs.

8.2   Future research and development requirements

In terms of methods for local flood risk assessment, future research and development effort should focus in the areas discussed in Section 4.5. To recap, these include:

- Rigorous, systems-based probabilistic analyses of local flood risk that build on the methods and tools developed by DTI SAM (HR Wallingford, 2009).

- Joint probability methods for describing interactions between multiple sources (boundary conditions) and complex pathways (hydraulic systems).

- Use of detailed hydraulic models in probabilistic flood risk assessment that build on the methods and tools developed by Defra/Environment Agency FCERM project *Methods for Local Probabilistic Flood Risk Assessment*.

- Methods for managing risk information at different spatial scales and levels of detail.

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List of abbreviations

1D	One-Dimensional
2D	Two-Dimensional
AAD	Annual Average Damages
ALC	Agricultural Land Classification
AStSWF	Areas Susceptible to Surface Water Flooding Map
CIWEM	Chartered Institution of Water and Environmental Management
DTM	Digital Terrain Model
FCERM	Flood and Coastal Erosion Risk Management
FMfSW	Flood Map for Surface Water
FRA	Flood Risk Assessment
FRI	Flood Risk Indicator
FRM	Flood Risk Management
FWMA	Flood and Water Management Act
GIS	Geographical Information System
HLM+	High Level Method Plus
IDB	Internal Drainage Board
IPR	Intellectual Property Rights
IT	Information Technology
IUD	Integrated Urban Drainage
LLFA	Lead Local Flood Authority
MCM	Multi-Coloured Manual
MDSF2	Modelling and Decision Support Framework 2
NRD	National Receptor Dataset
PFRA	Preliminary Flood Risk Assessment
R&D	Research and Development
RASP	Risk Assessment for System Planning
SFRM2	Strategic Flood Risk Management Framework 2
SuDS	Sustainable Drainage System
SWMP	Surface Water Management Plan
WaPUG	Wastewater Planning Users Group
WaSCs	Water and Sewerage Companies

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