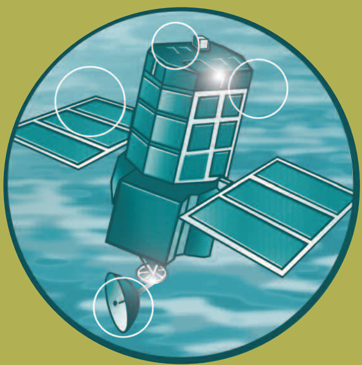
Defra/Environment Agency
Flood and Coastal Defence R&D Programme

Flood Risks to People

Phase 2 Project Record

FD2321/PR



Environment Agency

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

R&D OUTPUTS: FLOOD RISKS TO PEOPLE

Phase 2 Project Record

FD2321/PR

March 2006

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Statement of use
This is one of three final technical reports for Flood Risks to People Phase 2 project. It describes the development of the final methodology including the methodology for mapping risks to people.

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This document is also available on the Defra website
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John Goudie	Defra (Flood Management)
David Moses	Local Authority (Emergency Planning)

Other Key Consultees

Richard Horrocks	EA (Regional Flood Risk Management / REUU TAG)
Paula Orr	EA (Environmental Policy – Social Policy)
Sarah Lavery	EA (Flood Risk Management - Thames Estuary)
David Richardson	Defra (Flood Management - Policy)
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EXECUTIVE SUMMARY

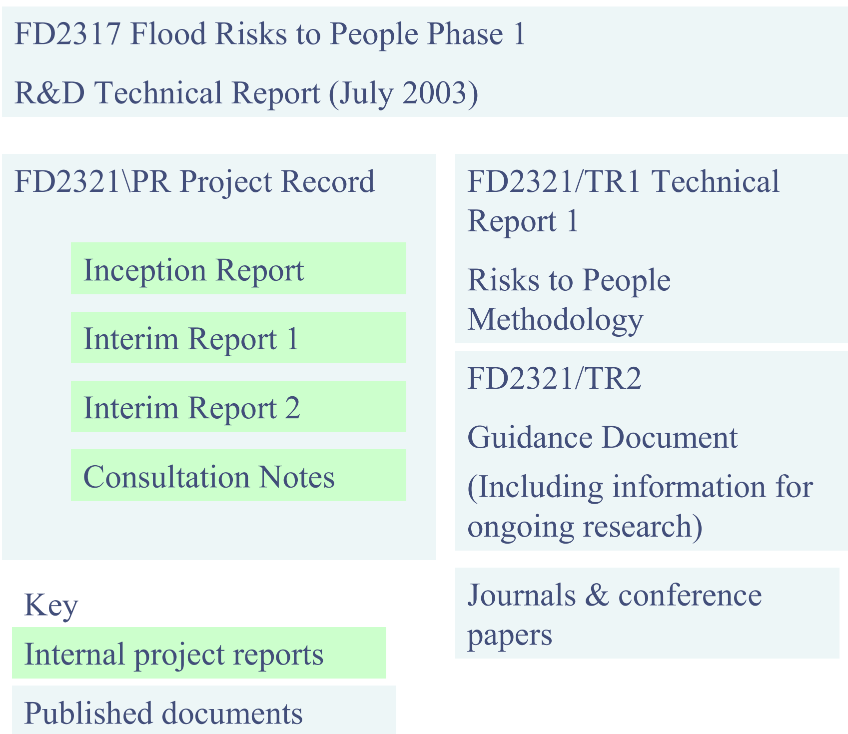
The overall objective of the Flood Risks to People project is to develop a methodology for assessing and mapping the risk of death or serious harm caused by flooding. The project covers death or serious harm to people that occurs as a direct result of the flood either during or up to one week after the event.

The project facilitates Defra's and the Environment Agency's move towards flood risk management. It fits within the Agency's Flood Risk Management Strategy and the Government's ideas presented as part of the consultation "Making Space for Water" on the Government's new flood risk management strategy.

The project was divided into two phases. Phase 1, which was completed in July 2003, was concerned with evaluating existing knowledge and developing the overall framework for the project. Phase 2 was concerned with providing more detailed research on flood hazard rating and the concepts of "Area" and "People Vulnerability" that describe the criteria required to assess the risk of death or serious harm due to flooding.

This document is the Project Record for Phase 2, collating the information from the Phase 2 Inception Report and Interim Reports 1 and 2. This Project Record is intended to inform the Project Board and other stakeholders involved in the project on all the research that has been carried out in Phase 2 in order to arrive at the final methodology and conclusions. It does not present new information but collates and summarises the information given in these previous reports. <u>The final methodology and associated guidance are provided in FD2321 Technical Report 1 and 2.</u>

Figure ES1 Summary of project documents



A comment on the concepts of 'tolerable' and 'acceptable' risks

In the UK there have been various Government reports that have developed the concepts of 'tolerable' and 'acceptable' risks, most notably the Health and Safety Executive reports 'Tolerability of Risk' (HSE, 1992) and 'Reducing risks, protecting people' (HSE, 1999). These advance upper limits of tolerability for annual individual risk for workers in 'risky' occupations and for the general public. If the annual risk of fatality or serious harm is less than the 'tolerable' risk it is deemed 'acceptable.'

Suggested thresholds for 'tolerable' and 'acceptable' risk have been used in several case study examples in this report and were discussed in Phase 1 of the research project (HR Wallingford, 2003). While these concepts are valuable, current Government policy for flood risk management does not consider a specific threshold for tolerable risk so the values used in this report should be regarded as illustrative only.

CONTENTS

Tables

Figures

1. INTRODUCTION

This report describes research on the Environment Agency and Defra “Risks to People” project. It collates research presented in the Inception Report and Interim Reports 1 and 2 and is intended to give the Project Board and other stakeholders a comprehensive record of the research that has been carried out on the project in the course of working towards the final conclusions. This report does not present the final methodology; this is included in the final Technical Report.

The following information is presented in this report:

- Section 2. Programme. This section describes the programme of work undertaken for Phase 2 of the project.
- Section 3. Project Overview. This section outlines the findings from phase 1 and the technical background of the project.
- Section 4. Consultation. This section describes the discussions that took place with various stakeholders within the Environment Agency and other organisations.
- Section 5. Scope of work. This section describes the actions for research arising from the consultation process.
- Section 6. Restatement of the Risks to People Methodology. This section describes the methodology proposed in Phase 1.
- Section 7. Flood Hazard. This section discusses flood hazard research that has been carried out during phase 2. Consultation has shown that there is an interest and need for guidance on issues such as “safe access and exit” and “development behind defences.” Flood hazard research completed in this project will inform Risks to People guidance and ongoing research on other projects, such as FD2320 on Strategic Flood Risk Assessment.
- Section 8. Area Vulnerability and the effectiveness of flood warning. This section presents research completed by the Flood Hazard Research Centre (FHRC) and Risk & Policy Analysts on Area Vulnerability and the effectiveness of flood warning in reducing risks to people. It is based on a literature review and interviews completed as part of Risks to People and a parallel FHRC “Roadtesting” project, designed to test the FHRC Multi-coloured Manual for use within the flood and coastal defence community.
- Section 9. People Vulnerability. This section presents phase 2 research completed by FHRC on People Vulnerability and describes the relevant factors that could be included in a People Vulnerability Index (PVI) based on census data and local information.
- Section 10. Other activities. This section records other relevant activities, such as links with other Environment Agency and Defra ongoing projects.
- Section 11. Conclusions. This section presents some conclusions as reported in Interim Report 1.

2. PROGRAMME

The project programme started in October 2003 with a three month Inception Phase that involved extensive consultation with EA staff and other stakeholders. Individual work packages on flood hazards, Area Vulnerability and People Vulnerability were completed by research teams from HR Wallingford, the Flood Hazard Research Centre and Risk & Policy Analysts Ltd.

The research project is due to to finish at the end of March 2005. The programme is shown on Figure 2.1.

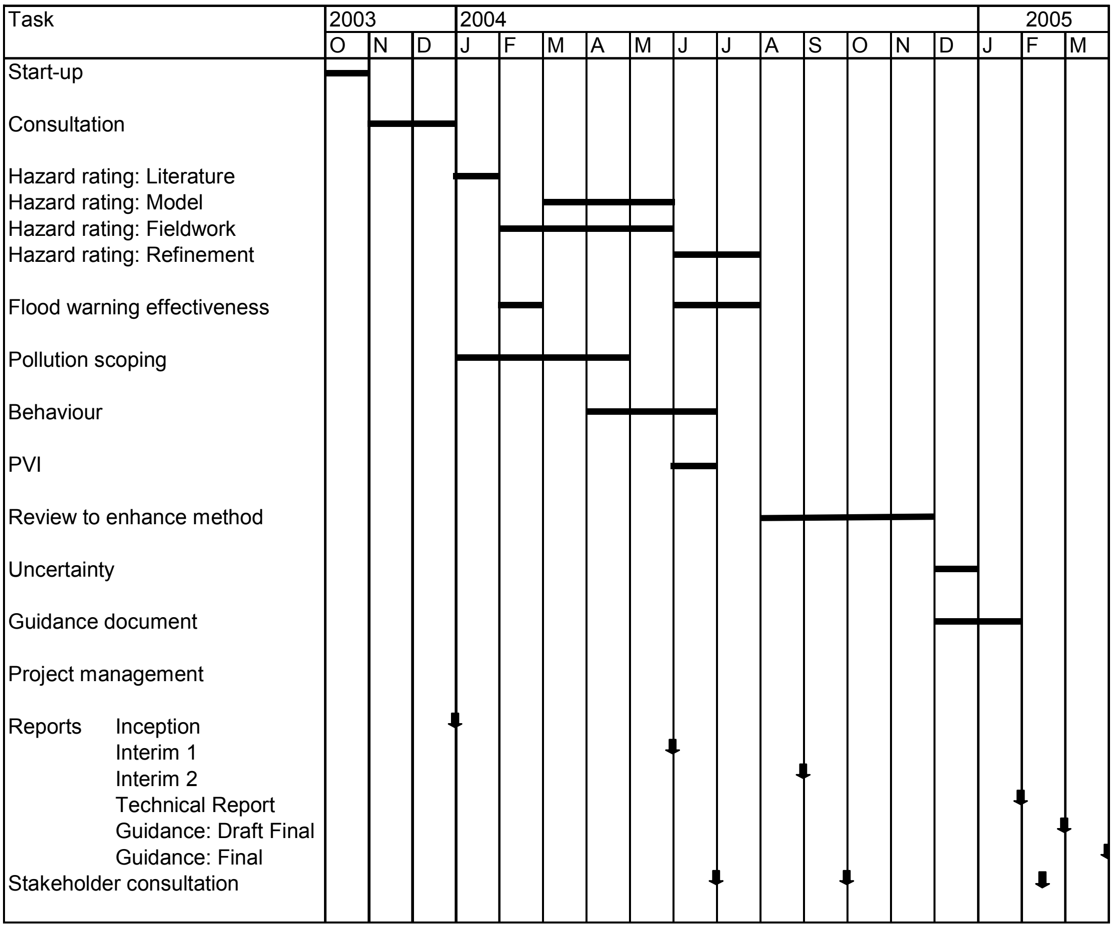


Figure 2.1 Project Programme

3. PROJECT OVERVIEW

3.1 Background

The project covers death or serious harm to people which occurs as a direct result of the flood either during or up to one week after the event, as follows:

a) death (usually drowning) as a direct and immediate consequence of deep and/or fast flowing floodwaters;
b) physical injuries as a direct and immediate consequence of deep and/or fast flowing floodwaters; and
c) deaths/physical injuries associated with the flood event (but occurring in the immediate aftermath).

Deaths/injuries in category (c) could well be independent of the nature of the flood event. For example, on hearing a flood warning, an elderly resident may struggle with moving a heavy piece of furniture and suffer a heart attack irrespective of whether the property is actually flooded at all. On this basis, whilst some data may emerge from the case studies, it should be recognised that such data could represent background 'noise'.

The project is being carried out in two phases. Phase 1, which is complete, identified the factors leading to flood risks to people and developed a methodology for assessing flood risks to people. The purpose of Phase 2 is to undertake the research needed to fill gaps in information and produce a refined methodology. The main output of Phase 2 will be the overall method for assessing flood risks to people that is suitable for mapping, together with a guidance document.

This project forms part of Defra and the Environment Agency's move to flood risk management. It links directly with the Agency's Flood Risk Management Strategy and Defra's emerging strategy for Flood and Coastal Risk Management[1]. In addition it is consistent with the Flood Risk Management Framework that proposed a tiered approach to risk analysis[2]. The methodology developed in Phase 1 can be tailored for risk mapping at different scales depending on the availability of suitable data.

The potential beneficiaries of the project include:

- All those involved in emergency planning and response, by providing information on areas where the greatest risks to people exist. These include the Environment Agency flood warning and emergency response staff, emergency planners, the emergency services, and local authority staff involved in flood response;
- The Environment Agency flood mapping strategy, by providing methods for flood hazard and vulnerability mapping;
- The Environment Agency flood plans for reservoirs, by providing a method for mapping flood hazard and flood risks to people;

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[1] Defra's Flood and Coastal Risk Management Strategy is currently under development. For more information see:- http://www.defra.gov.uk/environ/fcd/policy/strategy.htm

[2] This was an output of the EA/Defra Risk and Uncertainty Review (Defra project FD2302).

- Defra and Environment Agency staff and others involved in the planning of new flood defences, by enabling assessment and raising awareness of the possible changes in flood risks to people resulting from the construction of defences;
- The Environment Agency's national flood defence byelaw review, which includes such issues as 'safe' distances behind defences for development.
- Land use planning, by providing information on areas where there is a high flood hazard and therefore risk to people.

3.2 Objectives

The stated policy aim of Defra and the National Assembly of Wales is:

> *To reduce the risk to people and the developed and natural environment from flooding and coastal erosion by encouraging the provision of technically, environmentally and economically sound and sustainable defence measures.*

Their key objectives to achieve this policy are:

> *To encourage the provision of adequate and cost effective flood warning systems.*
>
> *To encourage the provision of adequate, economically, technically and environmentally sound and sustainable flood and coastal defence measures.*
>
> *To discourage inappropriate development in areas at risk from flooding and coastal erosion.*

The primary purpose of this project is to develop a method to assess the risk of death or serious harm to people caused by flooding. This will assist with:

- The planning and targeting of flood warning schemes by the Environment Agency, and emergency planning and response procedures by emergency planners and the emergency services. This will include the identification of "hotspots", where there is a high degree of flood risk to people;
- The planning of flood defences, by taking risks to people into account;
- Development planning, by taking risks to people into account in development proposals.

Thus this project will contribute to all three key objectives (see section 5.1 for further details). The specific objectives of the project are to:

- Review the factors leading to flood risks to people;
- Develop and pilot test a method for assessing flood risks to people that is suitable for mapping of flood risks;
- Provide a guidance document on flood risks to people.

3.3 Scope of Phase 2

The overall methodology developed in Phase 1 is summarised on Figure 3.1. Phase 1 identified a number of gaps in knowledge that are to be addressed by research to be carried out in Phase 2. Phase 2 also includes overall refinement of the methodology and preparation of a guidance document on flood risks to people.

The tasks to be carried out under Phase 2 are given in Table 3.1 below.

Table 3.1 Phase 2 project tasks

Task number	Task
1	Consultation
2	Flood Hazard Rating
3	Effectiveness of flood warning and other activities such as regulation & emergency planning
4	Impacts of water quality on flood risks to people
5	Behaviour of people during floods
6	People Vulnerability Index
7	Further testing and refinement of the methodology
8	Uncertainty in the results and confidence limits
9	Guidance document on flood risks to people
10	Information for ongoing research
11	Basis for flood hazard and vulnerability mapping

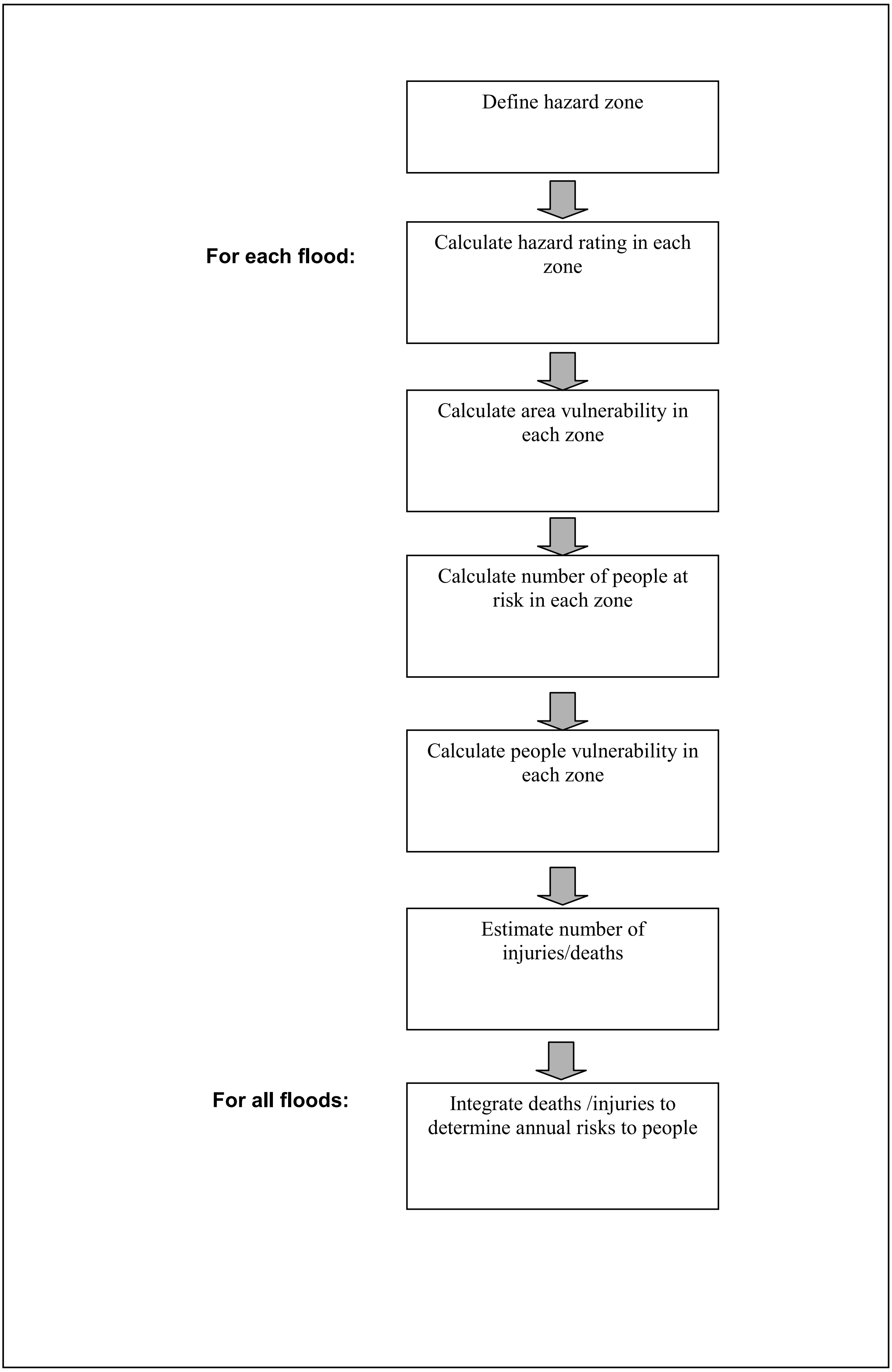


Figure 3.1 Overall methodology

4. CONSULTATION

4.1 Objectives of consultations

A certain amount of consultation was carried out in Phase 1, to ensure that the main users of project outputs were aware of the project and were able to contribute to the scope of Phase 2. This was done primarily by presenting the results of Phase 1 to the Project Board and receiving feedback on a draft of the Phase 1 report from the Project Board and other consultees.

It was however felt that further feedback should be obtained, based on the final report from Phase 1 and the proposal for Phase 2, to try to ensure that the research reflects the requirements of stakeholders.

The general approach to consultation was as follows:

- Inform consultees about the project;
- Find out the role of the consultee and his/her organisation, and how this relates to Flood Risks to people;
- Find out consultees' concerns regarding Flood Risks to People;
- Discuss how the project could assist consultees. This should include the type of information required by consultees, and how it should be presented;
- Identify ways in which the project specification could be adjusted to fulfil the requirements of consultees (to be reported in the Inception Report). At this stage there is no further budget available and therefore any changes should be minor (or increases in work balanced against a decrease somewhere else);
- Find out if the consultee wishes to be kept informed of project progress, and how this should be done. For example, the consultee could be sent copies of progress reports and other project outputs.

4.2 Consultees

The Consultees are listed in Table 4.1 below.

Table 4.1 Consultees

Consultee	Reason for consultation	Remarks
Mervyn Pettifor (Environment Agency)	Flood defence regulation	Meetings held on 23 October 2003
Ian Hope (Environment Agency national reservoir safety manager)	Implications for reservoir safety	Meeting held on 11 December 2003
David Murphy (Environment Agency)	Strategic planning (particularly mapping)	Meeting held on 2 December 2003
Tony Andryszewski (Environment Agency)	Flood warning	Meeting held on 10 December 2003

Table 4.1 Consultees (continued)

Consultee	Reason for consultation	Remarks
Phil Irving (Environment Agency)	Social acceptability and pollution	Meeting held on 25 November 2003
David Richardson (Defra)	Policy	Consultation by phone and email in January 2004
John Goudie (Defra)	Policy and appraisal	Consultation by phone and email in January 2004. (Already commented on Phase 1 Report)
Ian Meadowcroft (Environment Agency)	Risk approach	Consultation by phone and email in December 2003
David Moses (Hertfordshire CC)	Emergency planning	Meeting held in December 2003
Andy Dickson (Northamptonshire Police)	Emergency services	Meeting held in January 2004
Peter Bye	Local Authority Planning	Meeting held in December 2003
David Creighton	Insurance	Meeting held in December 2003
Paula Orr (Environment Agency)	Social issues	Consultation by phone in January 2004
Sarah Lavery (Environment Agency)	Thames estuary team	Consultation by email in January 2004
Richard Horrocks (Environment Agency)	Theme Advisory Group member	Consultation by phone in January 2004
Peter Von Lany	Theme Advisory Group member	Consultation by phone in January 2004 (Already commented on Phase 1 Report).
Jim Hall	Theme Advisory Group member	Consultation by phone in January 2004
Colin Green	Theme Advisory Group member	Consultation by phone and email in January 2004
Robin Spence (CURBE)	Effects of flooding on buildings	Meeting held on 5 December 2003

4.3 Key points arising from consultations

The main comments arising from the consultations are summarised below, together with a brief statement on how they might be taken into account in the project where appropriate.

General

- Many consultees thought that the project will be useful and wished to be kept informed of progress;

- The project must consider who the policy/process owners will be and how they will use the results.

  This is considered in Section 5.1

- Work with policy/process owners should continue throughout the project.

  Agreed, see Section 5.1

- The proposal envisages a stakeholder group. This has not been formed yet. Should it include flood victims or the National Flood Forum?

  See Section 5.1

- There is a vital difference between those who have had experience of flooding and those who have not, primarily in awareness. Those who are aware of floods realise how important it is to be prepared;

- The project has potential to contribute to the appraisal process by providing information on flood risks to people in a multi-criteria analysis.

  The project will provide a method for calculating risk under existing conditions using existing data sets. The method could be modified to calculate risk for proposed flood management schemes.

- The project will raise awareness of an important benefit of flood management that is not quantified at present (ie reducing risks to people);

- The project is primarily concerned with estimating flood risks to people under present conditions. The proposed map based outputs on flood hazard and flood risk (that will be developed from the results of this project) would however also be useful for development control purposes.

  See Section 5.1. Flood hazard mapping will identify areas where people would be at risk.

- The Agency would like to develop a risk based approach to all hazards, of which flooding is one. The approaches should be linked;

- Flood Plans are to be produced for all category A reservoirs (and a reduced version for category B reservoirs). These should include maps showing flood hazard and flood risks to people, which could be developed from this project.

  See Section 5.1

- There is a life insurance interest (not just flood damage insurance);

- The following groups have expressed interest in pilot testing the outputs: The Thames Estuary team, using both an existing developed area and a future development area and the North East Region flood warning team.

  See Section 5.1

Overall procedure

- What approach should we use for high hazard low probability situations (eg behind defences)? To produce an "Annual Average Risk" we will need to estimate the probability of defence failure (possible link with RASP project).

  To be considered in overall methodology, see Section 5.7

- Coastal flooding may need different factors in the algorithms developed in the project.

  To be considered in overall methodology, see Section 5.7

- Whilst the approach is considered reasonable for ranking areas of different vulnerability, concern was expressed about using this information to predict numbers of people because of the immense uncertainties in the method, and lack of supporting data. It is suggested that the results are presented in bands, with suitable descriptions.

  To be considered in overall methodology, see Section 5.7. Whatever method is used to present the outputs, the limitations and applicability of the data will be stated.

- There appears to be a 'human resilience factor' in which people survive more severe situations than might be expected.

  This will be taken into account in the overall testing of the method, see Section 5.7.

- The use of predictions from the method must be carefully considered. Will the results be good enough for planning/investment decisions? Is there a danger that if the risk is very low it would be ignored?

The limitations and applicability of the results will be stated. The project will indicate how the nature and magnitude of the risk should be made available to all who need to know. Potential funders also need to be advised of the levels of risk so that judgements on funding levels can be made. The level of risk needs to be recorded in a way that avoids the presumption that the smallest level of risk needs to be managed away.

- The probability of death could increase very rapidly with severity of flood. Is it possible to provide indicators of when it becomes significant? The danger is that people may think they are OK (from experience of a previous smaller flood) whereas in fact they are not.

  To be considered in overall methodology, see Section 5.7. There are many areas (for example behind flood defences, etc.) where low probability high consequence events could occur leading to a large number of deaths. The method should allow these locations to be identified.

Flood hazard

- It may be possible to derive a hazard rating behind defences based on head of water and distance from defence.

  To be considered in the overall methodology, see Section 5.7.

- Need to look for flash flood situations, not just where floodplains are large.

  This is covered by the methodology.

- Low points in cells are areas of high hazard, even if velocity is small. This is because they might fill up quickly.

  This is covered by the hazard rating.

- Flow velocities derived from mapped information will not take account of locally high velocities in streets between buildings.

  To be considered in hazard rating methodology, see Section 5.2. It may be possible to use a factor to increase velocities in urban areas, to take account of the blockage caused by buildings, etc.

- How to consider blocked culverts, etc.

  Account will be taken of the Agency's work on predicting flood risk areas caused by blockages.

- The police are aware that people cannot stand in 0.15m of very fast flowing water;

- Should we consider different flood frequencies or simply identify areas where risks to people could occur. Guidance is needed on where people need to worry (and where they need not worry). For example, those behind flood defences need to worry in large events where overtopping or breaching could occur. Those in flash flood areas need to worry whenever there is an extreme rainfall event.

  To be considered in overall methodology, see Section 5.7.

Area vulnerability

- The Area Vulnerability score includes fixed features of the area (eg housing) and a measure of the effectiveness of measures to manage the risk (eg flood warning). It is suggested that these are separated into two: a score for the vulnerability of the area based on physical features, and a score for the effectiveness of risk management measures. The second score could be a negative number: the greater the effectiveness, the smaller the sum of the scores and the overall Area Vulnerability.

To be considered in the overall methodology, see Section 5.7.

- Method concentrates on resident population. How can roads, railways and areas where people congregate (eg schools, supermarkets) be taken into account?
  This could either be taken into account in the area vulnerability score or in the population at risk. To be considered in overall methodology, see Section 5.7.

- Local knowledge is needed to determine area vulnerability, for example location of bungalows, etc.

  At a high (national) level it is intended to derive area vulnerability from land use and other mapped information. However for specific sites (for example for project appraisal or emergency planning), specific local data will be needed.

- Secondary defences can be used to channel water away from areas with high vulnerability;

- Roads and evacuation routes that flood will increase area vulnerability;

- Areas of high vulnerability include caravan sites, bungalows, ground-floor flats, underground spaces (basements, underground car parks, underground stations, shopping malls, underpasses, etc.).

  To be considered in overall methodology, see Section 5.7.

- Note that vulnerable people often live in bungalows and first-floor flats (for the obvious reason that they may not be able to climb stairs).

  To be considered in overall methodology, see Section 5.7.

- How is it proposed to deal with isolated properties where access is difficult, as the risk can be disproportionately high? Should area vulnerability include availability of support?

  To be considered in overall methodology, see Section 5.7. This could not be taken into account in a national assessment based on available mapped data, but could be considered at a local level using local data.

Flood warning

- The key customer is likely to be the head of Flood Event Management;

- Only a proportion of the population are in flood warning areas (about 60% has been suggested by the Environment Agency). Only a proportion of the population in flood warning areas actually receive a warning. It has been suggested that the figure might be as low as 20 to 30%;

The hazard will not change. Flood warning provides risk to life reduction opportunities. The shortcomings of flood warning systems should be recognised and the need for backup warning considered.

- A risk-based approach is needed for flood warning. For example, areas such as Canvey Island are below sea level (and therefore flooding could occur on every high tide). A risk-based approach is needed to decide when to issue a warning (rarely) and when to evacuate (very rarely);

- The project could add flood hazard and areas of high risk to people to the Agency's local flood warning plans (which are generally is based on IFM) and Local Authority Emergency Plans.

  See Section 5.1

- The Agency considers that a minimum warning of 2-hours is needed to gain financial benefit. A warning of say 15 minutes is very much better than nothing in reducing risks to people, but longer lead times are needed (to assemble assistance teams).

  This will affect flood warning effectiveness, see Section 5.3.

- The project could help to provide advice on actions to take for people behind defences (eg evacuate on receipt of warning, etc.) and evacuation routes;

- There are many small settlements in upper catchments that do not receive warnings because warning time is short. This is true even in chalk catchments where one would not expect high rates of runoff.

This will affect flood warning effectiveness, see Section 5.3. It may not be possible to provide reliable warnings in these areas at present.

- The project will help to identify settlements where there is a significant risk to people, and help the Agency justify providing warnings where they cannot at present (for example, upland settlements at risk of flash flooding).

Emergency planning, response and post flood recovery

- The emergency services and their LA recovery colleagues (Social Services) would benefit from knowledge of where flood risk to people is potentially high to assist with planning and prioritising their emergency response and minimising risks to their staff.

See Section 5.1

- The project will help to inform responses to emergencies (eg which roads to close, what to tell rail operators, etc.);

- The project will also help to alert emergency planners to the circumstances that lead to vulnerable people becoming even more at risk (e.g. old peoples' homes in floodplains).

  Information on concentrations of vulnerable people (usually available from Councils) should be plotted on hazard maps. The People Vulnerability index will only provide general information.

- Evacuation rates are slow and it is a hazardous operation. In addition, there is often a lack of willingness to evacuate, and the risk to life of rescuers increases the overall risk to life.

Development and Regulation

- There is an important link between risk to life and development control decisions;

- Awareness is needed of situations which can turn a non-threatening situation into a threatening one, for example building defences or a flood storage scheme.

  This should be covered in the Guidance Document.

- The Agency requires an assessment of the impact of flood defence regulation on flood risks to people. This is covered under Task 3 (Table 3.1). The outcomes of regulation include, for example, improved access to properties in flood risk areas, raised floor levels, maintenance of open areas behind defences, etc.

  The project is concerned with assessing existing flood risks to people. Identifying areas where flood defence regulation has been applied would be difficult without local knowledge. It may be possible to develop a procedure to assess the effects of flood defence regulation on flood risks to people, to be included in the Guidance Document, see Section 5.3.

- Project could provide advice on where to locate and where not to locate properties behind flood defences (especially coastal defences).

  This could be included in the Guidance Document.

- The project should link with other relevant work in this area including CIRIA Report 675, which provides guidance for developers, and R&D project FD2320, which is providing guidance on the assessment of flood risk for new developments.

- It is recognised that there is very little (if any?) evidence of the impacts of regulation on flood risks to people.

This means that any method to estimate the effectiveness of regulation on flood risks to people cannot be calibrated, and would therefore be very approximate. The project could however provide advice on the data that should be collected to calibrate and therefore improve the method.

Water quality

- Chemicals can have a serious impact during flood events but pollution does not usually cause death;

- Does this include gas bottles/tanks, which float and can explode?

  See Section 5.4

- Fires can occur during floods.

  See Section 5.4

- Is electrocution an issue?

  See Section 5.4

- The Agency manages a wide range of environmental risks. It is acknowledged that standards differ. Most of the risks to people are long term impact rather than death;
- The Agency is moving towards a 'risk based' approach for all hazards;

- It would be helpful if the R&D identified what pollution could cause death or serious harm (eg tar truck at Northampton; arsenic spills).

  See Section 5.4

Behaviour of people

- The project can link to the Agency's flood awareness campaign, particularly by giving advice on what to do (and what to avoid) during floods.

  See Section 5.1. This advice could be provided in the Guidance Document.

- A high proportion of deaths result from walking/driving through floods;

- Behaviours include recklessness and lack of awareness. Also 'sheep like' behaviour can be dangerous, where people fail to respond because others are not doing so.

People vulnerability

- A definition of vulnerability of 'people who are unable to evacuate themselves' is suggested (ie the old and disabled);

- The frequency of flooding is a factor in people vulnerability;

- The Agency is undertaking work on environmental quality, linking environmental deprivation with social deprivation. Helen Chalmers is the Agency project manager;

- Social conditions change over time in a particular area.

  This highlights the need to update information.

- The national census data is too broad brush to be useful for emergency response (although it may be OK for national planning). The emergency services use local information on where groups of vulnerable people live (eg sheltered housing, etc.).

  The national data will be used for broad brush national/regional assessments. Local information should be used for more detailed local assessments.

- The emergency services want to know specifically where vulnerable people are when planning emergency response.

  The project will not provide this detailed information but will contribute to the development of a map-based framework for assessing flood risks to people. Detailed local information could be added as required.

- The Agency is undertaking research on how to provide flood warnings to vulnerable groups.

Uncertainty

- There is a lack of data for calibration, contributing to large uncertainty. The project can influence the data collected during a flood (for example, assessments of flow velocity).

  See Section 5.8.

Guidance document

- Is it possible to provide guidance on assessing the effects of regulation on flood risks to people?

  It may be possible to develop a procedure for assessing the effects of flood defence regulation on flood risks to people, to be included in the Guidance Document, see Section 5.3.

- Guidance should link with developing parts of the Agency's Management System (AMS);

- The guidance document could include an example of a town, showing how to assess risks to people and how to plan for emergencies using this information.

Information for ongoing research

- Ongoing research including PAMs, RASP, MDSF etc. is intended to support Defra/Agency policy and planning. If the project is to provide information to these projects, the project leaders should be consulted to ensure the information is expected and well received.

  See Section 5.10

Mapping

- Need to ensure mapping proposals link with the Agency's flood mapping strategy.

  This is taken into account, see Section 5.11.

- The project outputs should link to key dates in the flood mapping strategy.

  This will be taken into account, see Section 5.11.

- There should be consistency in mapping methods, data sources, etc..

- Maps need to be detailed to be useful.

  The level of detail and accuracy is a major issue in flood mapping. The project results will be suitable for a high-level national/regional assessment. This will not provide accurate local detail and a local assessment using local information would be needed. The project results will identify 'hot spots' (areas of high flood risk to people), but local information may be needed to provide an accurate assessment of risk.

- The hazard information and maps could be linked to suitability of flood protection products.

  This may be possible to some extent. The main factor is flood depth as the products have a limited depth range. Ideally flood depth maps for a range of return periods are needed.

- Current mapping methods (from which flow velocity and depth could be derived) generally do not consider defences (eg IFM and EFO). It may be possible to modify them to do so.

  This is a major constraint to flood hazard mapping using existing maps, because some of the greatest hazards exist behind defences. See Section 5.2.

- The Extreme Flood Outline (EFO) method could provide velocities and depths subject to review of the accuracy of predictions.

This appears to be the most suitable source of national data for flood hazard mapping although it does not include defences. The project will use the whole range of available maps from the flood mapping programme.

4.4 Impacts of the consultations on scope of work

The scope of work for Phase 2 was largely agreed during Phase 1, but the consultations have highlighted user needs and to some extent altered the emphasis given to different project outputs. In particular, consultees have requested guidance on how to make assessments of flood hazard and flood risks to people using local data as this information will be useful in prioritising flood warning, emergency planning and emergency response activities.

Taking the results of the consultations into account, the expected outputs from the project can be summarised as follows:

- A method for calculating flood hazard that could be applied:
  a) Nationally or regionally using mapped data held centrally by the Agency;
  b) Locally, using local data on flow velocity and flow depth where available.

- A method for estimating flood risks to people that could be applied:
  a) Nationally or regionally using mapped data held centrally by the Agency;
  b) Locally, using local data on area vulnerability, people vulnerability, etc.

These methods will be set out in the Guidance Document. Technical information on the research (including testing of the methods) will be contained in a separate Technical Document.

Mapping of flood hazard and flood risks to people is not included in this project. Several stakeholders require mapped information, and this must come from other subsequent work. Sample maps will be provided for illustrative and testing purposes.

It must be recognised that national/regional outputs using mapped data will provide an overview of flood risks to people but will be subject to a high degree of uncertainty when applied at local level because of the approximate nature of the data.

Where specific local information is needed, for example to prioritise flood response activities, local data must be used (for example, locations of vulnerable people, etc.).

5. SCOPE OF WORK

5.1 Consultation

Whilst consultation on the proposed research has been carried out at some length, it is recognised that some ongoing consultation will be needed. A number of consultees expressed interest in being kept informed of the project. It is proposed to provide these consultees with summaries of outputs and request comment and feedback.

In addition, it will be important to keep key policy/process owners informed of work that is of particular relevance to them. These stakeholders are listed in Table 5.1.

Table 5.1 Key stakeholders

Function	Relevant output	Contact
Project appraisal	Estimates of flood risks to people for multi-criteria analysis.	John Goudie (Defra)
Flood mapping	Information for hazard and vulnerability mapping.	David Murphy (Environment Agency)
Flood warning	Information on flood hazard and high risks to people for Agency flood warning plans (and Local Authority emergency plans).	Tony Andryszewski (Environment Agency)
Emergency planning and response	Information on flood hazard. Guidance on estimating areas of high flood risks to people using local data.	Andy Dickson (Northamptonshire Police)
Flood awareness	Information on what to do (and what not to do) during a flood.	
Flood defence regulation and development control	Guidance on how to assess the effectiveness of flood defence regulation. Guidance on aspects of flood defence regulation, for example, "safe" distances behind defences.	Mervyn Pettifor (Environment Agency)
Land use planning	Information on flood hazard.	

Table 5.1 Key stakeholders (continued)

Function	Relevant output	Contact
Flood plans for reservoirs	Methods for mapping flood hazard and flood risks to people.	Ian Hope (Environment Agency)
Pilot testing	Application of methods to particular circumstances: • existing defended area • planned development area • flood warning	Kevin House (Thames Barrier Team) (Environment Agency) Tony Andryszewski (Environment Agency)

The project will provide the methods to fulfil these User needs, as discussed in Section 4.4. It will be necessary to agree the way in which project outputs are to be provided to each stakeholder. It should be noted that the following activities which are essential to achieve User requirements are not covered by the project:

- Selection of the source of flood hazard data for hazard mapping;
- Development of the flood hazard mapping procedure for national and local application;
- Use of RASP or other relevant model results for the calculation and mapping of flood hazard behind defences;
- Selection of data sets for mapping flood risks to people;
- Development of the procedure for mapping flood risks to people both for national and local application, including development of GIS tools;
- Identification of information on the effect of flood defence regulation in minimising the increase of risk by controlling new developments in flood risk areas. This is required to test and calibrate any guidance on the effectiveness of flood defence regulation produced in the project.

It is assumed that national mapping of flood hazard and flood risk to people will be undertaken by the Environment Agency. It is also assumed that any local mapping using local data will be undertaken locally by the Agency or Local Authorities.

5.2 Flood Hazard Rating

Introduction

The phase 1 report outlined a simple model of flood hazard based on velocity, depth and the presence of debris:-

Hazard rating = d(v+1.5)+DF

d typical depth (m)
v typical velocity (ms-1)
DF 0-2 score described the likelihood of debris

This type of model can be applied to different zones, based for example on distances from the river/coast or flood outlines of known return periods.

The specific equation presented in the Phase 1 report was selected to illustrate the process of hazard rating and further work is required to develop a more robust model for application in the UK.
One of the objectives of Phase 2 is to review and, if necessary, refine this calculation. Essentially, this will involve reviewing available data from a range of sources to ensure that the estimate of the HR is a 'true' measure of the potential of particular flood characteristics to result in physical harm to people. By way of example, in the Phase 1 Report, reference was made to the PhD thesis of Kelman and further publications on the effects of floods on buildings by Kelman and his colleagues (at the Cambridge University Centre for Risk in the Built Environment - www.arct.cam.ac.uk/curbe). These will be reviewed. In addition, work on wave overtopping and public safety on coastal structures undertaken by HR Wallingford will be reviewed.

Approach

Following the (abridged) bullet points in the Phase 2 proposal, the approach to this part of the study includes the following:

- A detailed review of previous research taking account of the "realism" of experimental work.

The Phase 1 literature review showed that there was limited data available from experimental, theoretical or case study-based studies on the safety threshold values of parameters describing the physical conditions of a flood. However during the inception period of Phase 2, several new sources of experimental data from the UK, Europe and US were identified by the project team. These include data from the recent experiments completed by FHRC for the BBC, which investigated the depth-velocity relationship that a person can stand up in, and by HR Wallingford's European partners on the EU IMPACT project. All the available data will be collated into a database for model development.

The realism of this experimental work will be critically reviewed considering:

- Whether the "flood victims" were standing or walking through the simulated flood water.
- The nature of the substrate (solid flume, slippery surfaces?).
- The use of harnesses and other safety equipment that may increase stability.
- The turbidity conditions (i.e. was the river bed or base of the flume visible?).
- The expertise and fitness of the volunteers, e.g. a stunt man was used in the BBC experiment.
- Development of a simple mathematical model of the stability of people in floodwater.

A simple model can be developed empirically based on the available data. Depending on the outcome of this work, it may be possible to (a) extrapolate the model for risks to people and (b) to develop complimentary models for building collapse and the movement of vehicles using theoretical relationships between hydraulic conditions, drag forces and sediment ("or person?") transport.

- Limited experimental work to fill gaps in the data.

Limited experimental work may be required to fill any gaps in the existing data set, e.g. for deeper, slower flood flows. Depending on the exact outcome of the review and Health and Safety considerations, HR Wallingford's physical laboratory facilities can be used for testing people's stability at different velocities and depths.

Any experimental design should involve people standing and walking as past experience indicates that people can resist flows while standing still but will be knocked over when they attempt to move. It could involve people of different age\gender\fitness\weight to test whether any demographic information could be used to modify the hazard rating.

- Building collapse

Finally further work will also be completed on building collapse and the movement of vehicles. This will include a review of research to identify thresholds for movement of different types of buildings and vehicles (e.g. caravans, bungalows, brick structures, cars) linked to velocity and depth of floodwaters.

- Debris

The debris factor will be reviewed and refined based on any experimental or empirical information identified in the research.

Indicative outputs

The outputs of this part of the project will be a revised hazard rating equation that has been tested against the available data.

Consideration will also be given to the factor needed to increase flow velocities in urban areas to compensate for the blockage caused by buildings (and the resulting higher local velocities in streets).

Links to other parts of the project

The hazard rating equation will form part of the overall Risks to People model as before.

The new work on debris, building collapse and vehicle movement may create other links with the Area Vulnerability Rating. Thresholds of velocity or depth may make building collapse or movement more likely in some areas, e.g. areas with caravan parks. The effect of introducing these kinds of linkages will be considered in detail as part of the refinement and testing of the overall Risks to People model.

5.3 Effectiveness of flood warning and other activities such as regulation and emergency planning

Introduction

The purpose of this approach is to consider the effectiveness of flood warning systems in reducing flood risks to people, in order to support the development and design of flood warning, awareness-raising and educational activities.

In the Phase 1 Report, flood warning was accounted for in the area vulnerability (AV) score. Given the importance accorded flood warning by the Environment Agency (and others), there may well be merit in developing a separate 'main factor' for flood warning (and other 'risk reduction' measures) (so that the risk would be a function of hazard rating, area vulnerability, people vulnerability and flood warning).

Approach

The proposed phasing of research is shown in Table 5.2. It is proposed to link this research with parallel ongoing research on the effects of flood warning on the reduction of flood damages. The phasing of this work has been adjusted to benefit from the results of this research.

Phase 2 of the research will involve interviews with some Agency, Local Authority and Defra staff. The choice of interviewees (Table 5.2) will be cleared with the Agency's Project Manager, and will include flood warning and flood plain regulation staff within the Agency, local authority staff in development control and emergency planning, and staff in Defra who have responsibility for regulation and flood defence standards. We will also seek to use certain results from the parallel project for Defra/EA on the effects of flood warnings on the reduction in flood damages that will involve a large number of interviews with flood "victims".

Table 5.2 Flood warning effectiveness and loss of life and/or serious injury: Phasing of research

Phase	Description	Comments
1	Historical review of the effectiveness of flood warnings, regulation and emergency planning.	To concentrate on the loss of life and serious injury impacts/alleviation
2	Interviews with key players in the Agency, local authorities and Defra.	Up to 15 interviews will be conducted
3	Analysis of relevant data from the parallel "Roadtesting" project for Defra/EA on the effects of flood warnings on the reduction in flood damages.	These surveys will be finished by June 2004. The results from this Loss of Life project may be delayed in this respect to take maximum advantage of that other project.

Table 5.2 Flood warning effectiveness and loss of life and/or serious injury: Phasing of research (continued)

Phase	Description	Comments
4	Synthesis of the results	Need to fit in the overall methodology.

Indicative outputs

The outputs are summarised in Table 5.3.

Table 5.3 Deliverables from flood warning effectiveness, etc. and loss of life and/or serious injury element of the project

Deliverable	Description	Comments
1	A comprehensive analysis of the effectiveness of flood warnings, regulation and emergency planning from the historical review.	The target (not necessarily to be achieved) will be quantitative and qualitative information.
2	Data and information for the application of the quantitative and qualitative information obtained to the overall refinement of the approach.	Will need judgement rather than just quantitative modelling.

The outputs may highlight the benefits of short warning times (less than 2 hours) which could lead to a change in Agency policy for providing such warnings.

It is likely that there will be very little information available on the effectiveness of flood defence regulation. The output may therefore consist of a method for estimating the impact of flood defence regulation in the Guidance Document, that could be applied to new developments.

Links to other parts of the project

The effectiveness of flood warning will be identified as a separate variable in the overall methodology, to be applied in parallel with the Area Vulnerability score. It is expected that this factor will include other emergency response activities including emergency planning.

In theory, flood defence regulation would be one of the factors to be taken into account in the Area Vulnerability score. However, in practice, it will be very difficult to determine which areas have benefited from regulation. This will be considered in the overall refinement of the methodology (Section 5.7).

5.4 Impacts of water quality on flood risks to people

Introduction

In the Phase 1 Report, although consideration was given to nature of floodwater (see Table 5.1 of the Phase 1 Report), little consideration was given to the potential acute effects associated with the potential effects of flooding upon hazardous facilities. The Environment Agency has provided details of registered landfills, IPC, IPPC and COMAH within the indicative floodplain. There are a surprising large number of such facilities and it is considered that the presence of such facilities will need to be accounted for within the 'area vulnerability' score.

Approach

Water quality in this context means physical (e.g. debris and mudflow), biological (e.g. wastewater) and chemical (e.g. toxic, fuel oil and radioactive) elements. These may in certain circumstances, or in combination, produce risk to life and serious injury. These circumstances are likely to be few, and the risks small, but they need to be considered so that the approach in the project as a whole is comprehensive. Particular concerns might include explosions caused by electrical problems during floods, or displaced gas tanks.

The phasing of this part of the project is given in Table 5.4, and Table 5.5 gives the steps in the empirical phase.

Table 5.4 Phases of the pollution scoping element of the project

Phase	Description	Comments
1	International research and incident literature review	To concentrate on the loss of life and serious injury impacts of likely pollutants.
2	Investigation of pollutant risk (likelihood and severity).	See Table 5.5 below.
3	Development of indices and/or an algorithm to match the current Risk to Life methodology (i.e. 'area' characterisation for the pollutant variable).	Need to fit in with RPA thinking as to how the overall methodology will evolve in this project.

Table 5.5 Investigative stages within the pollution scoping element of the project

Step	Description	Comments
1	Identify and categorise COMAH (top tier), IPC/IPPC and wastewater treatment work sites within the total population in the floodplain that have the potential for major pollution incidents.	Contacts already supplied by Agency Project Manager, who requests that we look at "concentrated pollution through other pathways (aerosol)": this may not be possible.
2	Investigate data on the Agency register for a sample of the sites identified in step 1 to determine potential health/life risks from exposure to these pollutants.	Access to Register via Ian Haskell (Agency).
3	Combine Step 1 data with information on the health risks of a key list of pollutants (determined from literature and event reports) and seek to rank the major installations and other sites according to the most likely source of the hazard.	Ranking will probably be in categories of site/pollutant (i.e. not 1 …n, but A, B, C categories).
4	Devise a simple typology of pollutants/ COMAH/IPPC sites and a hazard rating that can be used in the Risk to Life methodology (i.e. to (i) identify and (ii) map the risk zone).	Need to integrate with the thinking of RPA (Pete Floyd). May also need to consider operational causes, for example, shut down of facilities during a flood.

Indicative outputs

The overall deliverables are listed in Table 5.6.

Table 5.6 Deliverables from the pollution scoping element of the project

Deliverable	Description	Comments
1	Area characteristics for pollutant hazard.	Will set out the circumstances where and when pollutants are a risk to life and serious injury.
2	List and hazard ratings of pollutants likely to be significant in terms of loss of life and serious injury.	Linked to COMAH register and its data elements.
3	Contribution to the RPA-developed algorithms for flood character and area character.	Need to fit in with RPA thinking as to how the overall methodology will; evolve in this project.
4	Cameos of the circumstances where pollutants might be a risk to life or cause serious injury.	

Links to other parts of the project

It is likely that pollution would contribute to the Area Vulnerability score. However this will be considered in the overall review of the methodology. Pollution incidents causing a risk to life during a flood may have a very different probability to other factors that make up the Area Vulnerability, leading to distortion of the Area Vulnerability score. An alternative approach would be to provide guidance on how pollution could affect the predictions of flood risks to people.

5.5 Behaviour of people during floods

Introduction

An issue of particular concern is the loss of life that occurs as a result of the behaviour of individuals during floods. Whilst this is difficult to predict and quantify, it is nevertheless a significant factor. Better knowledge of behaviour in the event of flooding, and the links between behaviour and risk, could help to target risk awareness messages. The purpose of this approach will be to investigate incidents of injury/loss of life due to the behaviour of people during floods, and propose a method for taking this into account in the overall methodology.

Approach

Human behaviour in floods (and other disaster situations) can create self-imposed risks. This behaviour is often seen as "irrational" (e.g. people driving cars into rivers;

individuals attempting to cross fast-flowing streams and rivers) but this may not be the case. The purpose of this part of the research is to examine incidents when there has been loss of life and serious injury in floods to better understand motivations and actions. An attempt will be made to determine whether there is any modification to the overall project approach that will allow this data to be incorporated. The approach is summarised in Table 5.7.

Table 5.7 Phases of the human behaviour element of the project

Phase	Description	Comments
1	Analysis of the statistics of injury and loss of life in historic floods.	Initially concentrating on the UK, then Europe and also the rest of the world (the latter only in outline and where relevant to UK situations).
2	Synthesis of the above data and information for application (if possible) to the overall project approach.	

Indicative outputs

The overall deliverables are listed in Table 5.8.

Table 5.8 Deliverables from the human behaviour element of the project

Deliverable	Description	Comments
1	Statistical analysis of injury and loss of life in historic floods.	It is unlikely that the sample sizes will be large enough for very sophisticated statistical analysis.
2	Assessment of the potential for a contribution to the overall refinement of the approach	Will again need judgement rather than just quantitative modelling.

Links to other parts of the project

The intention will be to contribute to the overall calculation of deaths/serious injuries caused by flooding. For example, if any sort of statistical link can be established between the number of people who die because of self-imposed risks and the total number of deaths, this could be used to enhance the total number of predicted deaths.

Information on behaviour that leads to flood risks to people will be collated and presented in the Guidance Document. This information may be useful to the Environment Agency and others when providing guidance to the public on what to do and what not to do during floods.

5.6 People Vulnerability Index

Introduction

A Social Flood Vulnerability Index (SFVI) has been produced for the MDSF process within Catchment Flood Management Planning, based on community characteristics derived from census and other data. The Risks to People methodology takes account of the vulnerability of people at risk of flooding. The purpose of this approach is to investigate whether a measure of 'People Vulnerability' can be established for use within the overall methodology.

Approach

The same approach as was used in the SFVI will be used. An attempt will be made to develop a "People Vulnerability Index" (PVI) to gauge the extent to which individuals are vulnerable to the effect of floods and the way that they pose risks to life and cause serious injury. The proposed phases of the research are shown in Table 5.9.

Table 5.9 Phases of the "People Vulnerability Index" (PVI) element of the project

Phase	Description	Comments
1	(a) International research and incident literature review; (b) Review of past FHRC studies	To concentrate on the factors that lead to loss of life and serious injury: the people characteristics.
2	Seeking a correlation between loss of life and serious injury in floods and a number of human (individual) characteristics: e.g. age; health; access to and from neighbours; etc.	Will again need judgement rather than just quantitative modelling
3	Development of an Index to match (i.e. fit in with) the current Risk to Life methodology.	We must recognise that this may not be possible, or it may be very little different from aspects of the SFVI.

Indicative outputs

The overall deliverables are listed in Table 5.10.

Table 5.10 Deliverables from the "People Vulnerability Index" (PVI) element of the project

Deliverable	Description	Comments
1	Report from the literature review and review of past FHRC studies.	This literature is likely to be sparse, but we know that past FHRC studies are substantial.
2	Statistical or qualitative analysis and the development of the "People Vulnerability Index" (PVI) and examples of that Index.	This PVI may be very little different from aspects of the SFVI.

Links to other parts of the project

The PVI will replace the vulnerability assessment in the Phase 1 methodology. It is likely that it would be applied using national census data for national/regional assessments of risks to people, but more detailed local information would be needed for local assessments and emergency planning.

5.7 Further testing and refinement of the methodology

Introduction

A complete methodology for assessing flood risks to people was developed during Phase 1. It includes a range of assumptions based on experience that allowed the method to be demonstrated. The purpose of this approach is to:

- Review the assumptions;
- Refine the methodology; and
- Test the methodology using a wider range of case studies to ensure that the results are reasonably reliable in a range of different situations.

Approach

The aspects of the methodology to be refined include:

- Definition of hazard rating, to be developed as outlined in Section 5.2 above;
- Definition of area vulnerability, possibly including the effectiveness of flood warning and impacts of pollution, based on the work outlined in Sections 5.3 and 5.4 above;
- Definition of people vulnerability using the work outlined in Section 5.5 above;
- Incorporation of the behaviour of people during floods, based on the work outlined in Section 5.6 above;
- The relationship between injuries and fatalities;
- Consideration of issues that have arisen in the consultation, including:
  - the effects of regular flooding on risks to people;

- whether flood probability should be considered, or results just presented for 'worst-case' scenarios;
- how to take account of rare but potentially catastrophic events (for example, a 'Lynmouth – type' flash flood);
- how to estimate flood hazard behind flood defences, for example using the approach illustrated in Figure 7.1 of the Phase 1 Report;
- how to take account of defence reliability and improvement in the estimate of hazard behind defences;
- how 'hot-spots' should be identified and presented;
- how to take account of places where people congregate (e.g. roads, railways, supermarkets, etc.) rather than just residential population;
- how to differentiate high vulnerability sites, particularly those below ground (underground car parks, etc.);
- the impact of lack of availability of support for flood victims, for example in isolated areas;
- particular features of coastal flooding;
- the approximate nature of the results, and how they should be presented.

Once the methodology has been refined, it is intended to apply it to several case studies. After which, the methodology will be re-refined to account for the findings of the case studies.

The precise number and location of the case studies has yet to be determined but at this early stage, candidate locations which have been put forward include the Mablethorpe-Skegness coast and the Thames Estuary (to include existing and future developments). Other locations will need to include areas at risk from rivers (both with and without defences) and include those with long and short-lead times (in order to explore the implications of flood warnings).

Indicative outputs

The primary output will be a revised methodology for assessing flood risks to people. It will have the same fundamental basis and structure as the method proposed in Phase 1, but will include the additions described above. The methodology will be suitable for application using national/regional maps for a high level assessment, and also for application at local level using local data.

Links to other parts of the project

This stage will use information from the research described in Sections 5.2 to 5.6 above, and provide a methodology which will be applied in the Guidance Document to be produced under Section 5.9 below.

5.8 Uncertainty in the results and confidence limits

Introduction

All risk assessments are subject to uncertainty. The greater the uncertainty, the broader the range in which the 'true' risk may lie (i.e. wider confidence limits).

The degree of uncertainty will vary from factor to factor used in the analysis. Apart from data uncertainties, there will also be uncertainties in the models used to estimate the hazard/risk from the various input parameters. The purpose of this approach is to provide users with an indication of uncertainty in the results.

Approach

Overall, it is considered that the degree of uncertainty can be rated objectively on a simple ordinal scale (for example, from 1 = little uncertainty to 5 = extreme uncertainty) and that these values can be associated with limits of confidence (for example, an uncertainty score of 2 might suggest 95% confidence limits of plus/minus 50% of the 'best' estimate of risk).

Estimates of uncertainty will be developed for different parameters of the process including the final estimates of flood risks to people.

Indicative outputs

The outputs will consist of uncertainty estimates for each parameter and combined parameters, together with a commentary on how the results should be applied. Prioritisation of high-risk areas based on the method is likely to be quite reliable. However the calculation of definitive values for the likely number of deaths/serious injuries will be subject to large uncertainty and this will affect the way in which the results should be used.

Links to other parts of the project

The uncertainty calculation will link to the calculated outputs from the overall flood risks to people methodology.

5.9 Guidance document on flood risks to people

Introduction

The purpose of this approach is to provide guidance on how to estimate flood hazard and flood risks to people, and procedures for identifying and prioritising high-risk areas.

Approach

A guidance document will be produced on the causes of flood risks to people and how these can be assessed and managed. Guidance will also be provided on mitigation measures where appropriate. It is likely that a case study will be included which will:

- Demonstrate the method of calculating flood risks to people;
- Demonstrate the process for identifying and prioritising high risk areas for flood warning and emergency planning purposes;
- Demonstrate how to apply the results for flood defence regulation and development planning.

The Guidance Document will also include guidance on specific concerns of stakeholders, including:

- Guidance on what to do and what not to do during floods;
- Behaviour that leads to flood risks to people;
- Information for flood defence regulation arising from the research, for example safe distances for development behind defences;
- Use of local data in assessing flood risks to people.

Beneficiaries of the guidance will include Agency flood warning, flood defence, strategic planning and development control staff, emergency planners, emergency services, local authorities and those affected by flooding.

Indicative outputs

The main output will be a Guidance Document for dissemination in paper and electronic formats.

Links to other parts of the project

The Guidance Document will contain the methodology in a format intended to facilitate use by stakeholders. The results of the research will be contained in a separate technical document.

5.10 Information for ongoing research

Introduction

The project links to a number of other ongoing research projects. The purpose of this approach is to ensure that the links are identified and developed so that optimum use is made of the research.

Approach

A document will be prepared summarising the relevant ongoing research projects and their links with the flood risks to people project. Information will be provided on specific links and the required exchange of information.

Relevant ongoing and planned projects include:

- The multi-criteria analysis approach proposed for catchment flood management planning. This type of approach is also being considered for project appraisal;
- The Modelling and Decision Support Framework (MDSF) for catchment flood management planning;
- Risk Assessment for Strategic Planning (RASP);
- Performance and Asset Management System (PAMS);
- Flood Foresight;
- Floodsite, a major EC funded project covering several aspects of flood risk;
- The new EPSRC funded co-ordinated research programme on flood management.

Indicative outputs

The summary document referred to above, and dissemination to those involved with relevant ongoing and planned projects. Contacts will be made with these projects to identify linkages during 2004.

Links to other parts of the project

Information from the Guidance Document and other research results will be referred to in the summary document.

5.11 Basis for flood hazard and vulnerability mapping

Introduction

The Environment Agency has developed a flood mapping strategy which includes the requirement for flood hazard mapping by December 2004. The purpose of this approach is to ensure that the outputs feed into the flood mapping strategy.

Approach

A summary document will be prepared containing a recommended approach to developing the Agency's Flood Hazard and Flood Vulnerability Maps based on the results of research carried out under this project. This will include recommendations for the mapping method and dealing with issues such as scale, accuracy and links with other mapping and data. Preparation of the document will include consultation with those involved in producing the Agency’s flood maps, particularly David Murphy (Agency), Jeremy Benn Associates and Halcrow/HR Wallingford.

Indicative outputs

The main output is the summary document referred to above.

Links to other parts of the project

This output will describe how the outputs of the project can be used to provide mapped outputs consistent with the Agency’s flood mapping strategy. This will lead in turn to implementation of the Priority 4 items listed in the CSG7 proposal form for the project, which were:

1. Mapping method for the flood hazard rating
2. Specification for GIS based mapping method
3. Development and trial implementation of GIS based mapping method
4. Pilot testing of the GIS based mapping method.

These items are not included in Phase 2 of the flood risks to people project.

6. RESTATEMENT OF THE RISKS TO PEOPLE METHODOLOGY

6.1 Overview

This Section provides an overview of the Phase 1 methodology and adds some further information on the sources of data required for the mapping of Flood Risks to People. The overall Flood Risks to People methodology was described in the Final Report of Phase 1 of the project (Environment Agency, 2003)[3]. This "re-statement of the methodology" is based on (a) the simple example used on the Phase 1 report and (b) a new example of local mapping of risks to people in Towyn, North Wales.

The methodology is based on three concepts:

- Flood Hazard Rating. This is dependent on the physical characteristics of flooding and typically involves mapping estimates of flood velocity and depth. In Phase 1 of the project, the Flood Hazard Rating was calculated as a function of velocity, depth and a debris factor
- Area Vulnerability. This is related to location characteristics, such as the nature of the housing stock (e.g. low or high rise buildings) or the use and effectiveness of flood warning
- People Vulnerability. This is related to the age, health and the behaviour of people during flooding.

Information on these three concepts is combined using a scoring system (form of multi-criteria assessment) in order to provide an estimate of the number of injuries or deaths for a given flood. The methodology can be applied at different scales for different purposes as indicated in Table 6.1.

Table 6.1 Application of methodology at different scales

Scale	Purpose	Data sources	Comments
Local	Emergency response	Detailed hydraulic models, "area" and "people" information from local authority and emergency services.	Provides maps to pinpoint areas of greatest risk and vulnerable people who need the help of emergency services. Can also provide information on safe evacuation and access routes to improve safety of emergency service and Agency staff.
Catchment to Regional	Flood risk and vulnerability mapping	Catchment models, CFMPs, MDSF, Regional Development Agencies	Linkages to catchment scale flood risk mapping, land use planning and targeting flood warning. The method provides more information

[3] The methodology was presented in Section 5 of the Phase 1 Final Report. Any cross-referencing to this report is indicated as a hash # followed by the Section number, e.g. #5.6.

Scale	Purpose	Data sources	Comments
			on receptors than mapping extents and flood levels.
National	Scenario testing, policy appraisal	RASP, Census data	Research needed to understand risks to people highlighted in Foresight. The method can be used nationally to test scenarios and policies.

In Phase 1 of the project the method performed very well when tested against three historic floods. Further work in Phase 2 will assess the uncertainty associated with the method and determine whether the results are presented as an estimated number of deaths/injuries or in simpler risk classes.

6.2 Flood characteristics

There is broad agreement that the degree of hazard associated with floodwater is primarily associated with depth and velocity. Therefore these are the two most important variables for mapping flood hazard. There are a number of other physical characteristics that may affect the stability of people, vehicles and buildings during flooding, such as the speed of onset (compared to flood warning), flood duration, nature of flood water and the presence of debris. Of these factors the presence of debris was considered in Phase 1 and a debris factor was included in the Flood Hazard calculation.

6.3 Location characteristics

At any particular time, people may be present in various locations:

- outdoors on foot
- outdoors in a vehicle
- indoors in a basement or (confined to) the ground floor
- indoors within a two-storey building
- indoors within a multi-storey building.

There are clearly different levels of risk associated with different locations e.g. areas with caravan parks and low rise property are more vulnerable than areas with permanent two storey or office buildings that, in most cases, provide safe areas above peak water levels during a flood. The Area Vulnerability concept classifies areas according to location characteristics that consider building stock, speed of onset of flooding and flood warning.

6.4 Population characteristics

Taking a particular flood in a defined area under specified circumstances (degree of flood warning, timing, etc.) will lead to an indication of the probabilities that people will be exposed to the flood. The probability that a particular individual will suffer serious short-term physical injuries will depend, to some extent, on their personal characteristics. We would expect the following:

- the very old to be more at risk

- the infirm/disabled/long-term sick to be at greater risk.

Although a young child theoretically would be at high risk, it is very unlikely that, say, a four year old would be left alone to deal with a flood.

More generally, assertions that direct physical injuries will be a function of other socio-demographic factors such as income, level of education, employment status, deprivation indices, family status, car ownership, home ownership, etc. are unsubstantiated. It is, however, accepted that such factors may influence the extent and impact of longer term physical and psychological effects associated with the aftermath of flooding. The People Vulnerability concept classifies people into Low, Medium and High risk classes based on age and the percentage of infirm, disabled or long-term sick compared to the national average.

6.5 Quantifying the relationships (exposure assessment) for a single event. Example from the Phase 1 Report

6.5.1 Methodology

The number of deaths/injuries is calculated using the following equation:

$$N(I) = N \times X \times Y.$$

Where:

N(I)	is the number of deaths/injuries
N	is the population within the floodplain
X	is the proportion of the population exposed to a risk of suffering death/injury (for a given flood)
Y	is the proportion of those at risk who will suffer death/injury.

The risk of suffering N(I) deaths/injuries will simply be the likelihood of the given flood.

In order to calculate N(I), there need to be methods to calculate X and Y and some methods are proposed below.

6.5.2 Determining those at risk

In order to estimate the numbers of people at risk, it will be necessary to estimate the degree of hazard by location within the floodplain. In essence, this will require determining the numbers of people (N(Z)) within different hazard zones (or grid cells) - where the degree of hazard is related to depth, velocity and debris. The first step is therefore to define the hazard zones.

In Phase 1 the following formula was used to combine velocity and depth:

$$(v + 1.5) \times d.$$

There is a risk when the velocity is zero and the depth is large, hence the addition of 1.5 to the velocity term. While this appears quite arbitrary this equation has been critically reviewed and tested as part of Phase 2 of the project and it appears to fit the empirical evidence as well as any other alternative equation (Section 7). A further factor for debris is added to reflect the degree of increased hazard based on experience of flood hazard estimation. A hypothetical example is presented in Table 6.2.

Table 6.2 Hazard zones and those at risk, N(Z)

Distance from river/ coast (m)	N(Z)	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating = d(v+1.5) + DF
0-50	25	3	2	2 – likely	12.5
50-100	50	2	1.8	1 – possible	7.6
100-250	300	1	1.3	0 - unlikely	2.8
250-500	1000	0.5	1.2	0 - unlikely	1.35
500-1000	2500	0.1	1	0 - unlikely	0.25

6.5.3 Determining those exposed

As discussed above, the numbers of people exposed will essentially depend on four factors:

- flood warning
- speed of onset
- nature of the area (type of housing, presence of parks, etc.)
- timing of the flood.

Defence overtopping and breaching are a special case, where the speed of onset can be rapid and, whilst severe conditions may be forecast, there may not be any warning of the actual flooding.

Although such factors could be calculated probabilistically, in Phase 1 a simple scoring system (on a three point scale) was used. There is scope for refinement of this approach in the next stages of the project, linking to flood warning effectiveness to the Area Vulnerability score. However the research to date suggests that the refinement will be based on how to score different areas (using the three point scale) rather than complicating the classification scheme (Section 8).

The scoring system used in this example is shown in Table 6.3.

Table 6.3 Area vulnerability

Parameter	1 - Low risk area	2 - Medium risk area	3 - High risk area
Flood warning[1]	Effective tried and tested flood warning and emergency plans	Flood warning system present but limited	No flood warning system
Speed of onset	Onset of flooding is very gradual (many hours)	Onset of flooding is gradual (an hour or so)	Rapid flooding
Nature of area[2]	Multi-storey apartments	Typical residential area (2-storey homes); (low rise) commercial and industrial properties	Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc.

Notes: (1) In this context, flood warning includes emergency planning, awareness and preparedness of the affected population, and preparing and issuing flood warnings.
(2) High and low 'nature of area' scores are intended to reflect the judgement of the assessor as to whether there are particular features of the area in question which will make people in the area significantly more or less at risk than those in a 'medium risk area'.

The sum of the factors (i.e. 3 to 9) provides an indication of the vulnerability of the area (as opposed to that of the people). This is shown in Table 6.4 for each of the hazard zones.

Table 6.4 Area vulnerability scores

Distance from river/coast (m)	Flood warning	Speed of onset	Nature of area	Sum = area vulnerability
0-50	2	3	2	7
50-100	2	2	1	5
100-250	2	2	3	7
250-500	2	1	2	5
500-1000	2	1	2	5

This area vulnerability score is simply multiplied by the hazard rating derived above to generate the value for X (the % of people exposed to risk) as shown in Table 6.5. Should the score exceed 100, this is simply taken as 100. Whilst this is not a true percentage, it provides a practical approach to the assessment of flood risk.

Table 6.5 Generating X (% of people at risk)

Distance from river/coast (m)	N(Z)	Hazard rating (HR)	Area vulnerability (AV)	X = HR x AV	N(ZE)
0-50	25	12.5	7	88%	22
50-100	50	7.6	5	38%	19
100-250	300	2.8	7	20%	59
250-500	1000	1.35	5	7%	68
500-1000	2500	0.25	5	1%	31

Note: N(Z) is the population in each hazard zone
N(ZE) is the number of people exposed to the risk in each hazard zone

6.5.4 Determining numbers of deaths/injuries

The final stage is to compute the numbers of deaths/injuries. This is achieved by multiplying the number of people exposed to the risk (N(ZE) from Table 6.5) by a factor Y which is based on the vulnerability of the people exposed.

Y is a function of two parameters: the presence of the very old; and those who are at risk due to disabilities or sickness. For the purposes of this analysis, the parameter values shown in Table 6.6 will be used. The number of parameters is currently under review.

Table 6.6 People vulnerability

Parameter	10 - Low risk people	25 - Medium risk people	50 - High risk people
the very old (>75)	%well below national average	%around national average	%well above national average (including areas with sheltered housing)
infirm/disabled/ long-term sick	%well below national average	%around national average	%well above national average (including hospitals)

The sum for each area then provides an estimate of the Y values for each area which are then simply multiplied by the numbers of people exposed to the risk (as derived in Table 6.5) to give the numbers of injuries. In the hypothetical example, assumptions have been made as to the percentages of the very old and infirm etc. present within each of the zones as shown in Table 6.7 in order to generate values for Y.

The resultant number of injuries is then simply the number of people at risk (from Table 6.5) multiplied by Y as shown in Table 6.8.

Table 6.7 Generating values for Y (people vulnerability)

Distance from river /coast (m)	Presence of very old	Factor 1 (10/25/50)	Presence of infirm, etc	Factor 2 (10/25/50)	Y = 1 + 2 (as %)
0-50	around nat'l average	25	around national average	25	50%
50-100		25		25	50%
100-250	above nat'l average	50		25	75%
250-500	below nat'l average	10	below nat'l average	10	20%
500-1000		10	around nat'l average	25	35%

Table 6.8 Generating numbers of injuries and deaths

Distance from river /coast (m)	N(ZE) Table 6.5	Y = 1 + 2 (as %)	No. of injuries	Fatality rate = 2 x HR	No. of deaths
0-50	22	50%	11	25%	3
50-100	19	50%	10	15%	1
100-250	59	75%	44	6%	2
250-500	68	20%	14	3%	0.5
500-1000	31	35%	11	1%	0
All			89		7

It would be expected that in zones with a relatively high hazard rating (which is a function of depth, velocity and debris), there would be an increased probability of fatalities. It has been assumed that a factor of twice the hazard rating is appropriate, expressed as a percentage. Applying this factor (as shown in Table 6.8) provides an overall result of a predicted 89 injuries of which 7 are fatalities.

6.5.5 Summary

The above analysis provides an illustrative example as to how the key factors which influence short-term physical injuries from flooding could be accounted for in determining the overall numbers of injuries.

Clearly, the methodology could be 'tuned' to more accurately reflect the relative importance of the key factors. However, it would appear that most of the parameters (or surrogates) for a particular floodplain are already available with the possible exception of velocity. The data requirement issues are discussed in Section 6.6.

6.6 Quantifying the relationships (exposure assessment) for a single event. Example of coastal flooding in Towyn, North Wales

An example calculation of Risks to People was completed for the town of Towyn, North Wales. This example highlights some of the mapping and GIS issues related to the project.

A LisFlood hydraulic model was available for a 1 in 200 and 1 in 1000 year overtopping and breach events for this area so both flood depth and velocity could be estimated over a 50 m grid for these events. The town has a vertical sea wall and promenade along the sea front and earth embankments along the river estuary. There are a number of areas with caravan parks that would be scored highly for Area Vulnerability (Figures 6.1 and 6.4).

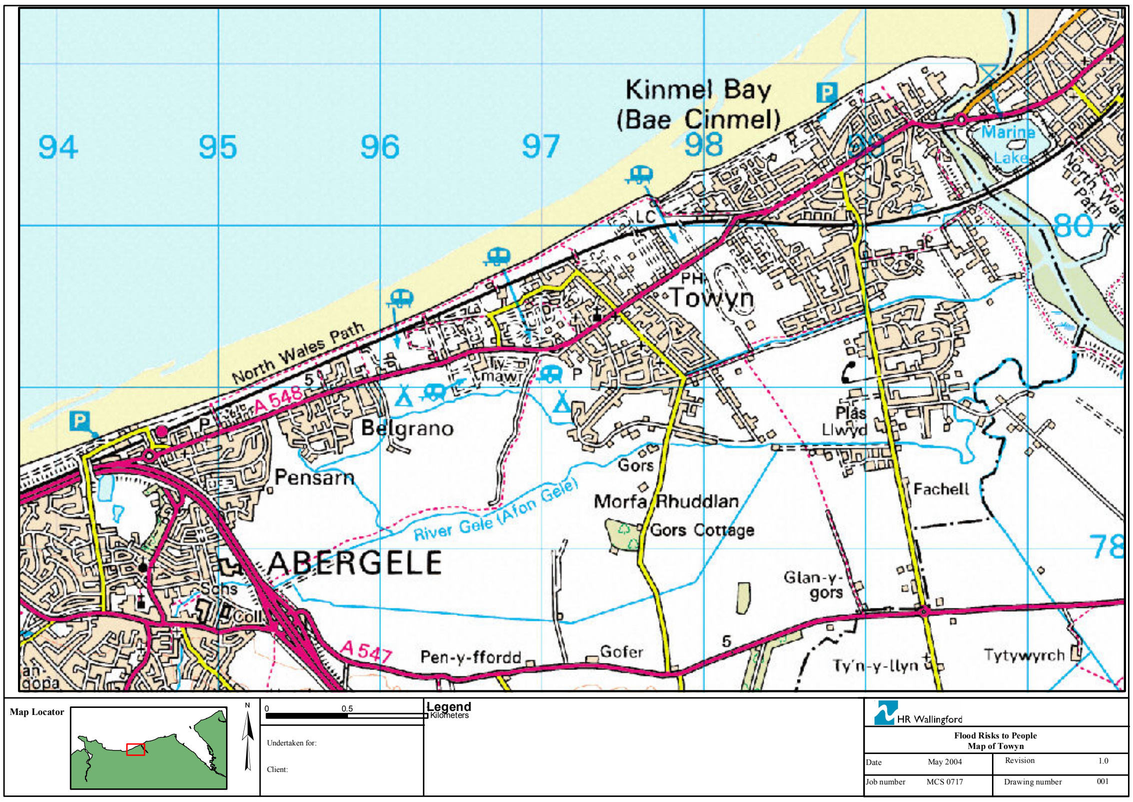


Figure 6.1 The town of Towyn, North Wales

The flood hazard rating for a 1 in 1000 overtopping event is shown in Figure 6.2. This calculation assumed a debris factor of zero. It is also possible to consider the risks associated with violent wave overtopping by buffering an area immediately behind the sea wall (see Section 7) and a map including this hazard is shown in Figure 6.3.

An Area Vulnerability map based on Table 6.3 was created that picked out the location of the caravan parks on the 1 to 10000 Ordnance Survey map (Figure 6.4). For Population Vulnerability it was assumed that all population was medium risk (Table 6.6). Figure 6.5 shows the population density derived from the ward scale census data applied to the built up urban areas. An arbitrary population was also applied to roads to account for people travelling in their cars (Figure 6.5)[4].

For a 1 in 1000 year overtopping event in Towyn the total number of deaths and injuries was estimated as 29 and 105 respectively.

This example highlighted a number of GIS issues regarding the derivation of Area and People Vulnerability maps at different scales. These issues will be discussed with stakeholders including the Environment Agency's National Centre at Twirton.

Table 6.9 Sources of data for mapping at different scales

	Flood Hazard	Area Vulnerability	People Vulnerability
Local	Velocity and depth estimates from detailed modelling. Wave overtopping considered if a significant local risk using the methodology reviewed in Phase 1 or more detailed work by Allsop *et al*.	Detailed Ordnance Survey (1:1250, 1:2500) mapping supplemented by local knowledge. All public places such as schools and hospitals considered in detail with estimates of the average numbers of people present (daytime/night time). Environment Agency flood warning area data.	Local authority and emergency service data on vulnerable people (age, disability etc.) and their locations.
Regional	Either (a) estimate depth and velocity from catchment scale flood mapping or (b) estimate flood hazard behind defences as a function of distance from source of flooding.	Regional OS data (1:10000 to 1 to 50000) Regional Development Agency information on land use. Environment Agency flood warning area data and catchment characterisation.	RDA data combined with national data sets
National	Estimate of depth from national assessments (e.g. RASP High Level). Velocity estimated as a function of distance.	National data sets.	Use of census data and national data sets such as the Social Vulnerability Index

[4] Note that the roads were simply derived from some national mapping and these don't fit the 1 to 10000 roads. Obviously more detailed road and rail network data are required for detailed mapping.

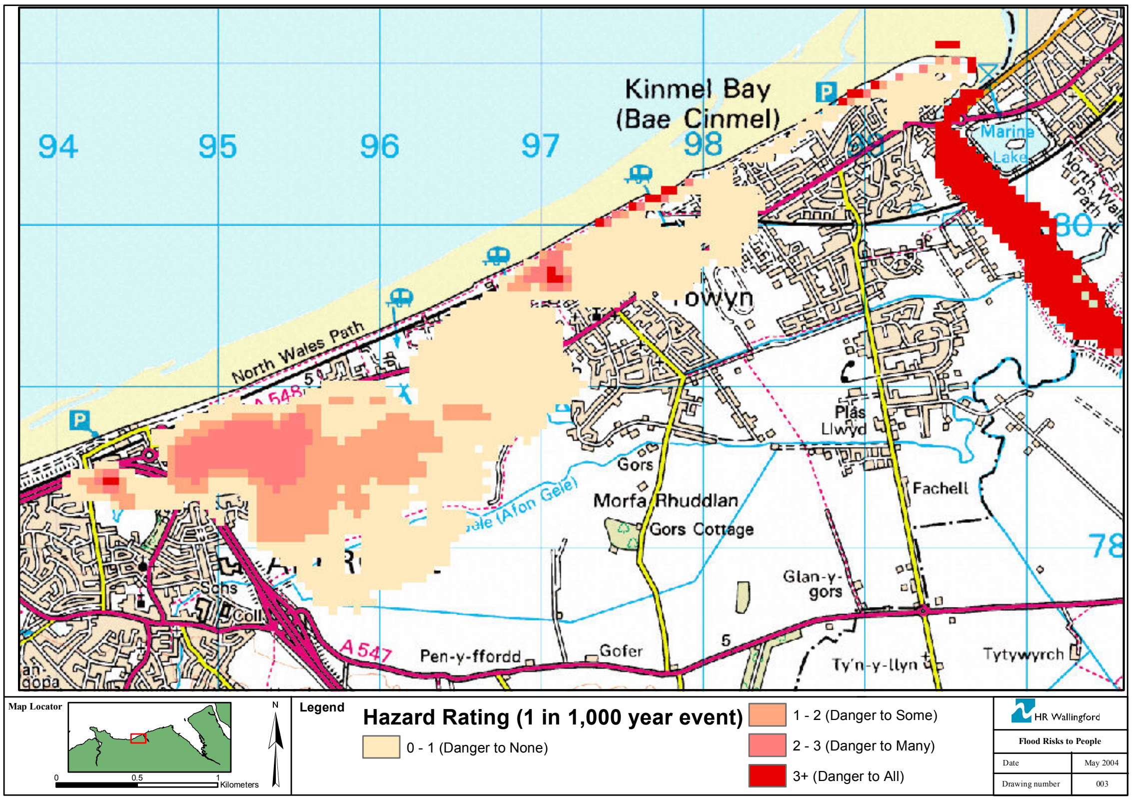


Figure 6.2 Flood hazard rating for Towyn

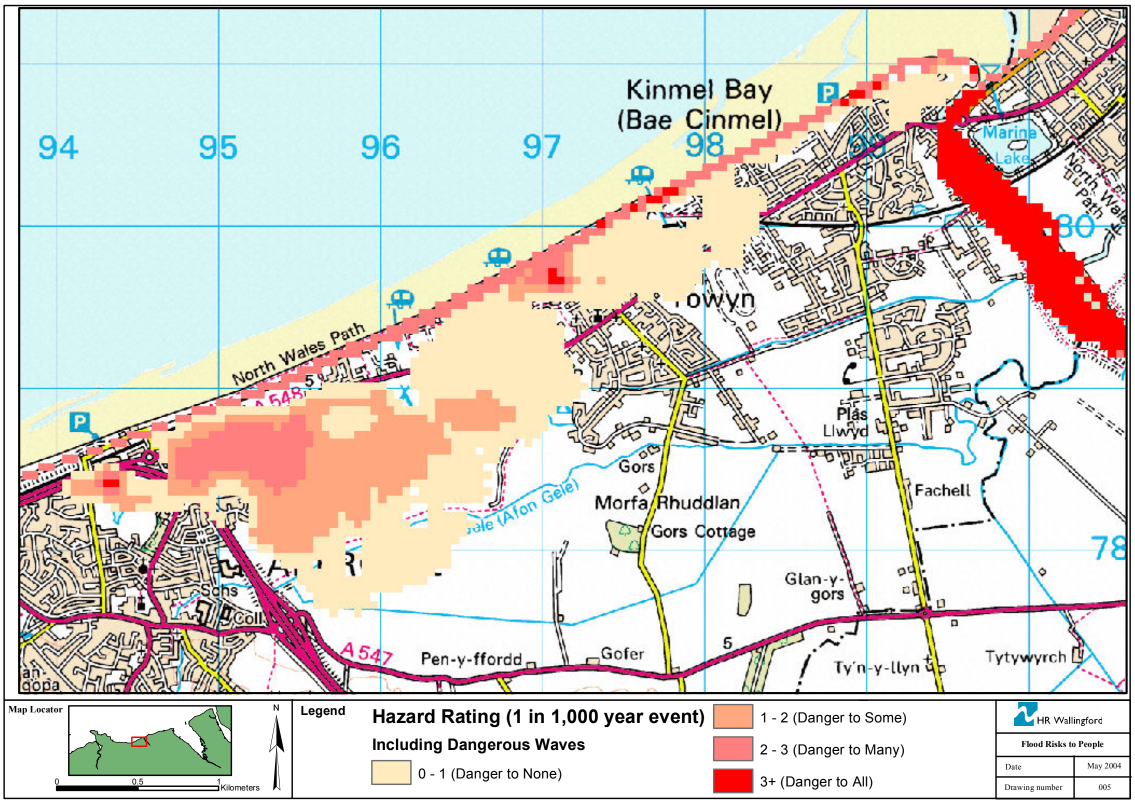


Figure 6.3 Flood hazard rating for Towyn including wave overtopping

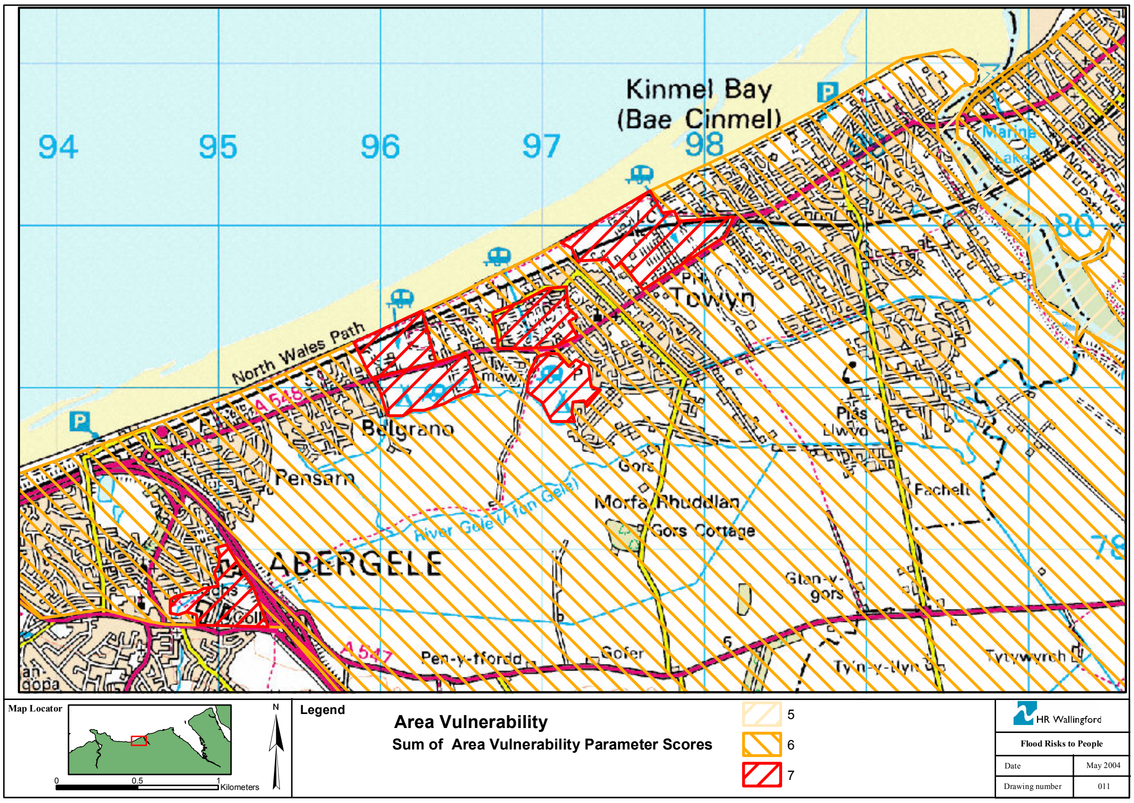


Figure 6.4 Area vulnerability (need a map here even if made up nos.)

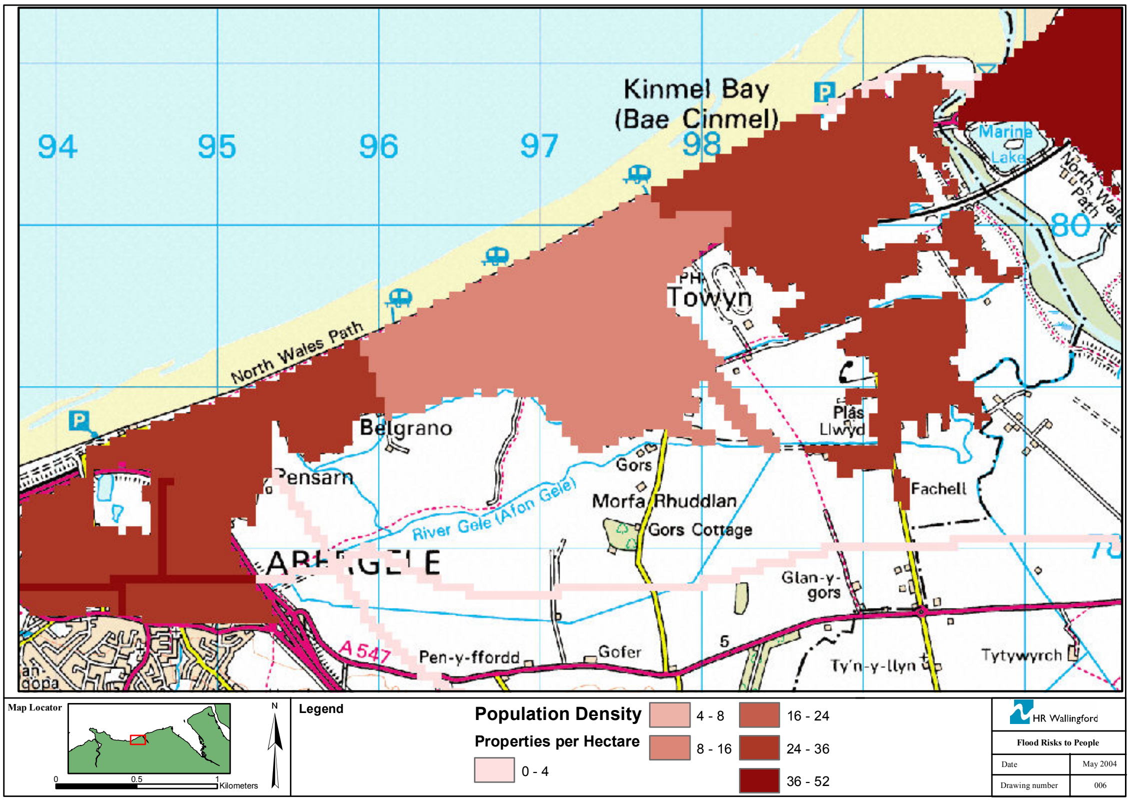


Figure 6.5 Population densities (all population assumed to be medium risk)

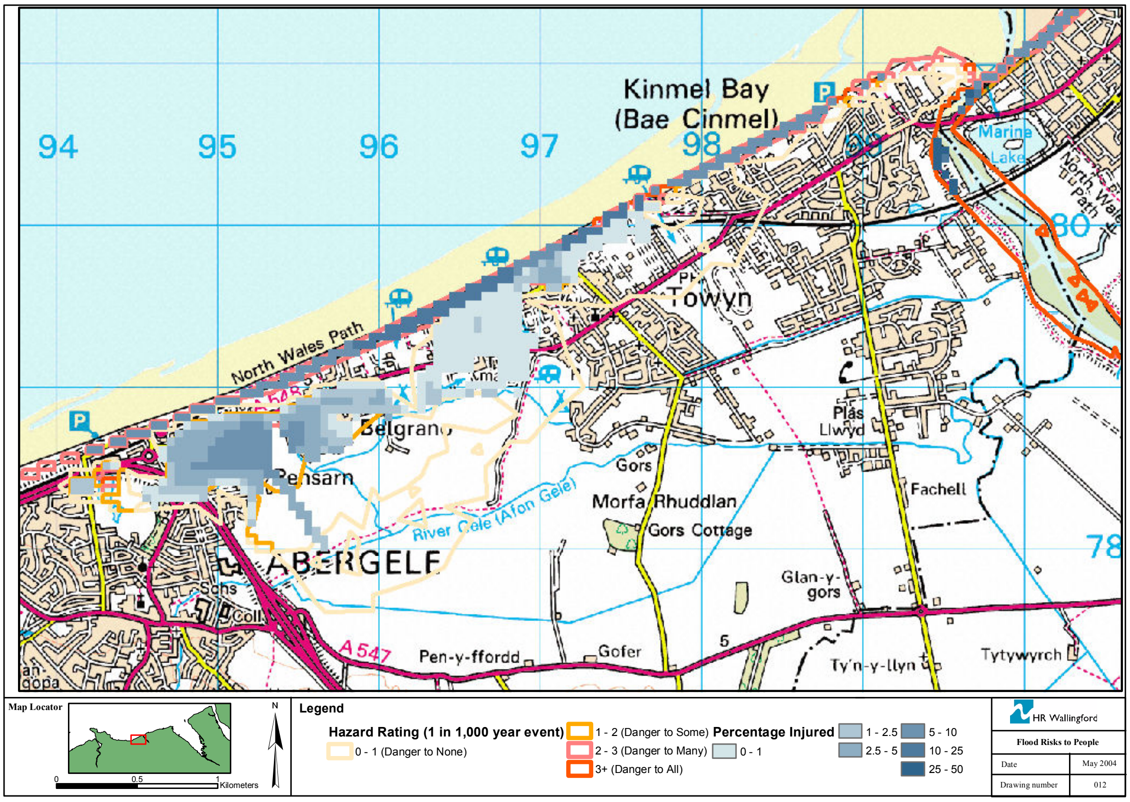


Figure 6.6 No. of injuries for 1 in 1000 year event

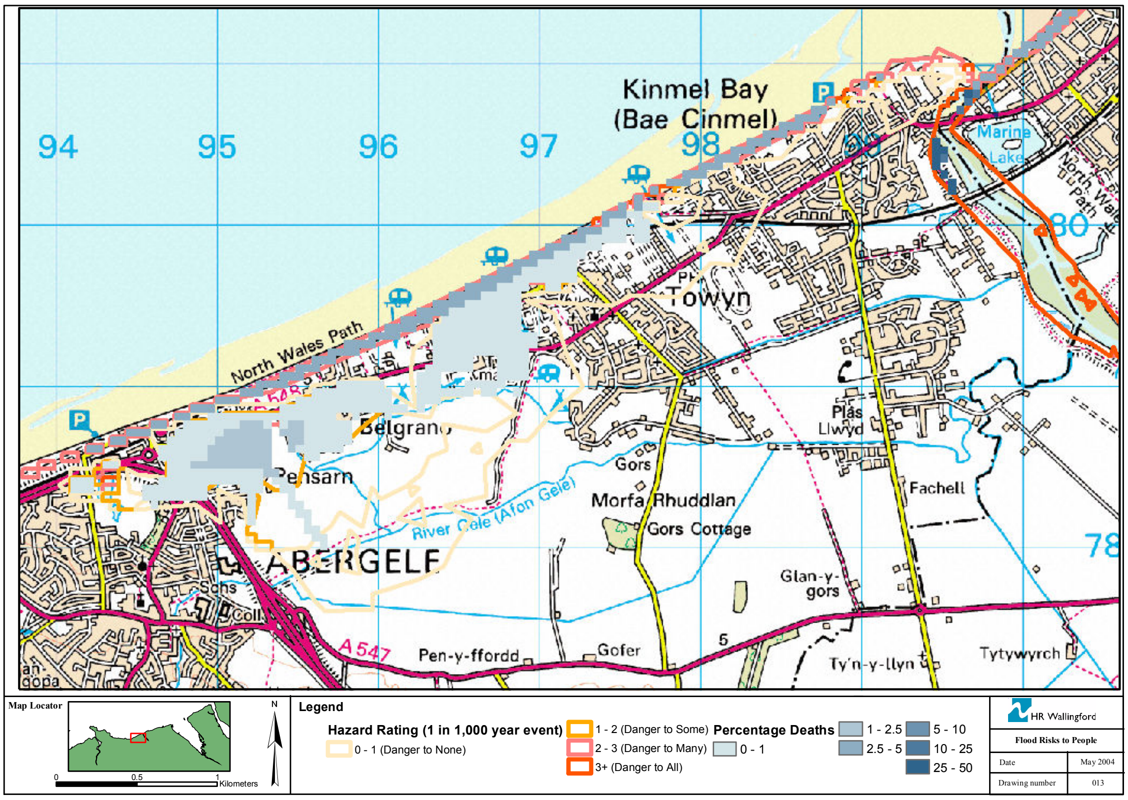


Figure 6.7 No. of deaths for a 1 in 1000 year event

7. FLOOD HAZARD RATING

7.1 Introduction

This Section describes the research completed on flood hazard rating. It includes:

- A review of experimental data from flume studies completed in US, Europe and Australia
- A theoretical analysis of the forces that cause toppling of people in flood water
- A simplified method for estimating flood hazards due to breach and overtopping behind defences where detailed models are unavailable
- Further consideration (beyond that in Phase1) of how to incorporate the risk of wave overtopping along the coastline in the mapping approach.

Following a review of experimental data from the US, Europe and Australia (Sections 7.2 to 7.5) it was clear that further experimental work using the flumes and flood channel facilities at HR Wallingford would not extend or improve the available data set. Therefore, our effort has focused on a detailed and critical review of the existing experimental data.

7.2 A review of hazard rating equations

The development of a hazard rating equation aims to quantify the seriousness of a flood hazard in terms of the characteristics of the flood, typically as a product of its depth and velocity.

Previous research in this area has resulted in different approaches to the problem. In general, other studies have attempted to define the most critical parameters and form integrated assessments based on these. The Flood Risks to People Project provides a separate analysis of three concepts; flood-hazard, area vulnerability and people vulnerability. This approach is flexible because the concepts can be applied to large areas for national and regional assessments. If there are some areas where more detailed data are available, for example, on velocities from a 2D model, the approach can be refined.

Previous work that has been carried out specifically on hazard ratings looks at the flood conditions in which a person will not be able to stand up and walk through the water, with the implicit assumption that if they fall over then they will drown and be killed, or be seriously injured. There have been three significant experimental programmes in this vein, which have physically tested human subjects in controlled flumes or channels to find loss of stability functions. The first of these studies was Abt *et al.* (1989), where flume tests were carried out for a range of velocity and depth conditions. Further experiments were then done by Helsinki University of Technology (2000) for the RESCDAM project and by the Flood Hazard Research Centre (FHRC) and the BBC in the UK (Penning-Rowsell, pers. com., 2004).

The following sections aim to outline the previous research into assessing flood risks to people by firstly giving an overview of the integrated analyses that have been derived, then by explaining the basis of two of the experimental studies. The critical review and analysis of this information supports the hazard rating approach that is proposed.

7.3 Integrated analysis

Integrated analyses of flood risk to people considers the problem by evaluating a number of different causal factors to risk. Each analysis has given a different priority to factors according to arguments presented on what has the most influence and on the interdependencies of factors. The factors determining the risk are also dependant on the situation for which the risk is being assessed. Different conditions and situations of flooding have therefore been studied by these research programmes in order to determine the most suitable methodology for risk analysis for each situation.

Work carried out by the Delft Cluster (Asselman and Jonkman, 2003) in the Netherlands was motivated primarily by the requirement to understand the risk to people living in the polders, areas of land lying below sea level. They define one of their most important factors as the effectiveness of polder evacuation. The Japanese research reported here aimed to understand risk from flooding that occurs as a result of general fluvial, coastal and rainstorm-induced flooding. They relate the risk to life to the number of inundated buildings with the aim of providing a framework that is more applicable in light of limited data that can restrict the use of direct methods that equate the risk to the flood characteristics and social vulnerability. Studies on the risk to people caused by dam break can also give an important insight into what determines the risk to people. The NATO project carried out by IST and LNEC in Portugal gave a useful analysis of risk to people caused by dam break and integrated several indexes of flood hazard and socio-economic factors in order to provide an overall, integrated assessment of flood risk.

7.3.1 Polder flooding

Asselman and Jonkman (2003) devised a framework for the estimation of loss of life caused by floods in the Netherlands. They took into account the characteristics of a flood and the effect of evacuation in their loss of life model and applied it using GIS.

A flood-mortality function is developed where the probability of drowning is related to hydraulic factors of depth, velocity and rate of water rise. The relationship is developed from an analysis of data from the 1953 floods in the Netherlands. The effect of evacuation was neglected since the flood occurred at night and there was no opportunity to evacuate. The study isolated the causes of mortality and gave functions for different situations. Two functions were developed to calculate the fraction of inhabitants killed in a flood for the two different cases of fast rising water and slow rising water.

$f(h)_{rise} = 9.18 \, . \, 10^{-4} \, . \, e^{1.52 \, . \, h}$ $\quad f(h)_{rise} \leq 1$ For when the water rises with 1 m/hr or more.

$f(h)_{other} = 1.41 \, . \, 10^{-3} \, . \, e^{0.59 \, . \, h}$ $\quad f(h)_{other} \leq 1$ For when water rises at a rate less than 1 m/hr.

Since there is no data for water depths of more than 3.9 m, the extrapolation of the first function may result in unrealistic mortality numbers for deeper water. The graphs for these regressions are given in the paper and it does not look like the correlations are particularly strong. No r^2 values are given for the relationships.

A further relationship was used to calculate the fraction of buildings that collapse and assumed that collapse would result in the death of all those present in the building. The analysis presumes that the factors that determine building collapse are depth and velocity. There are two options for the building collapse analysis. Firstly, TNO, a Dutch science and engineering consultancy, investigated the thresholds of velocity-depth combinations that result in a certain probability of building collapse for four different types of building structure. Secondly, and more simplistically, the RESCDAM project proposed that total collapse of masonry, concrete and brick buildings will occur when:

$vd \geq 7 m^2/s$ and $v \geq 2$ m/s

Asselman and Jonkman (2003) considered the effect of evacuation and reviewed two alternative approaches. The first was a detailed study by the Poldevac project, where a transport model was used to simulate evacuation, down to the level of accounting for cross roads and traffic lights. A model of this detail is, however, too complex to be able to be used on a national basis as it requires an extensive amount of data. The second approach was developed by Barendregt *et al*. (2002) and assumes that it takes a certain amount of time for the decision to be made to evacuate, then further time to carry out the evacuation. The percentage of people successfully evacuated will depend on the length of time available to go through this process before the hazard arrives, and so is therefore dependant on the warning time available before the flood.

Asselman and Jonkman (2003) developed a loss of life model in a GIS, taking into account these factors discussed. The flood characteristics of rate of rise, water depth and flow velocities are based on the hydraulic computations in the 2D SOBEK model. The GIS contains information on the location of high-rise buildings as that differentiates people who can find a safe place in their homes as the water level rises. The evacuation model relies on estimation of the time needed for complete evacuation and then the application of the Barendregt (2002) function. The number of fatalities is estimated using one of the three relationships depending on whether the location is affected by slow rising water, or fast rising water, or fast velocities (building collapse).

7.3.2 Fluvial, coastal and pluvial flood research in Japan

This paper develops a generalised flood injury risk function based on statistical data from fluvial, coastal and pluvial floods in Japan, where pluvial flooding is flooding that occurs as a result of water from rain ponding on surfaces, usually in urban areas, before it has a chance to enter the river. They argue that for a flood of a given severity, there is a percentage of fatalities in the total population and the remaining percentage are safe. The relative proportions of these two fractions depend on the severity of the flood. They define the severity of the flood by the number of inundated buildings. They find that injuries and fatalities increase after flood severity passes a threshold value. For the Japanese data, the thresholds are 1000 inundated buildings before fatalities occur and 100 inundated buildings before injuries occur. This presumes that the exposed population is proportional to the number of inundated buildings.

7.3.3 Dam break flooding

IST and LNEC in Portugal carried out this NATO-funded research to investigate dam safety and risk management in downstream valleys (Betâmio de Almeida, A., 2001). They develop a framework for assessing the risk for each potential event or hazard acting on the dam system. They present a formal risk concept where they account for the hazard occurrence probability, the conditional probability of occurrence of an abnormal flood induced by the dam response to hazard, and the conditional probability of loss of life along the valley due to the induced dam-break flood.

The research looks at dam safety legislation. It argues that the factors determining the risk to human lives and building collapse during a flood are; maximum depth and flow velocity, depth gradient with time, time of flood arrival and flooding duration. It concludes that the flood severity characteristics should be the basis for preliminary risk zoning.

A vulnerability index is given that consists of a flood hazard factor (so-called 'agressivity' factor) and a socio-economic vulnerability factor. The flood hazard factor is determined by the maximum flood depth, the maximum flow velocity, the flood arrival time after dam-break and the flood depth gradient. The function is defined as:

$$I_{PV,J} = \{ [K_1(DV^{\alpha})_M + K_2(D_M) + K_3(\Delta D/\Delta T)] / [K_4 (T_F^{\beta})] \}$$

The index is non-dimensional but needs to be calibrated for consistency. The socio-economic factor is calculated based on indexes of physical environment, sociology, economy and preparedness.

7.4 Hazard rating experiments and theory

The investigation of purely hazard rating indexes can be approached by carrying out physical experiments that test people's stability in different flood conditions and also by formulating theoretical arguments to represent the physics of the situation of a person in flood water.

The data from the physical experiments of Abt *et al*. (1989) and Helsinki University of Technology (2000), from now on referred to as the RESCDAM experiments, are examined in the following section. Abt *et al.* (1989) carried out flume tests in velocities 0.36-3.05 m/s and depths 0.42-1.2 m. The RESCDAM flume tests were carried out in velocities 0.6-2.75 m/s and depths 0.3-1.1 m. Further physical experiments have been carried out by FHRC and the BBC in the UK (Penning-Rowsell, 2004).

This section examines the procedures for the experimental studies that have been carried out in these research programmes to test the stability of a person in flood water. The conclusions the researchers made from their work are explained. In addition, both Abt *et al* (1989) and Keller and Mitsch (1993) have taken a theoretical look at the problem. They examine different mechanisms of the loss of stability of a body in water, resulting in three different expressions. The basis of their theoretical arguments is explained in this section.

7.4.1 Abt *et al.*, Colorado State University, 1989

The work by Abt *et al*. (1989) was the first physical flume experiment that examined the depth and velocity conditions that cause a person to fall over. Their research gives an analysis of some theoretical issues as well as the data gathered from the experiment programme.

The authors give a theoretical argument for an expression to describe the toppling hazard for a monolith. They take the monolith configuration to represent the human body structure with respect to flood exposure and measure the monolith dimensions and weight. An analysis of the forces acting on the body when subjected to flowing water is given; these forces are:

1. the weight of the monolith, W
2. buoyancy, B

   $B = (\text{thickness}) \times (\text{width}) \times (\text{depth of water}) \times \gamma_w$

   where γ_w is the unit weight of water

3. the dynamic force due to velocity, P

   $P = C_d \times \rho \times (v^2/2) \times A_n \times S_f$

where C_d is a coefficient of drag
ρ is the density of water
v is the average flow velocity
A_n is the area normal to the flow
S_f is a safety factor

4. surface friction, F_f
5. the hydrostatic upstream force, F_u
6. the hydrostatic downstream force, F_d

The rotational stability of the monolith in water depends on the resultant of the forces acting on the downstream bottom edge of the monolith. Toppling occurs when the force of the oncoming flow is greater than the moment due to the resultant weight of the monolith. The expression for the toppling hazard envelope curve is found by summing the moments about the downstream bottom edge of the monolith:

$$\Sigma_{Medge} = [(W - B) \times (1/2 \text{ thickness})] - (P\ (1/2d)] = 0$$

The resulting curve will be different for monoliths of different weights. The equation assumes that the monolith is standing upright on a stable foundation and that the velocity distribution is uniform in the channel.

Abt *et al*. (1989) compared their theoretical analysis with the results from flume experiments which tested the depth and velocity conditions under which instability of the monolith would occur. The empirical results were very close to the theoretical predictions, which validates the theoretical analysis. The drawback of the analysis is that it is for a monolith and not a person, and although carefully represented, the human subject will respond differently to a monolith in flood conditions. This was also shown with Abt *et al*.'s experiments.

In the same programme of research, the authors tested twenty human subjects in addition to the monolith. The people were observed in a flume under different depth – velocity conditions and with different bed surface types (turf, smooth concrete, steel, gravel) and different bed slopes. The analysis of the results aimed to quantitatively predict the point of instability of the human subject and it defined the causal factor as the 'product number', the product of depth and velocity. For the human subjects, the product numbers were found to be between 0.7 m^2/s and 1.94 m^2/s for channel slope 0.015 and between 0.93 m^2/s and 2.13 m^2/s for channel slope 0.005. With all else being constant, the product number for a human subject to become unstable is 60 to 120 percent greater than the product numbers resulting from the theoretical analysis and the monolith tests. The authors explained this by the difficulty in quantifying or reproducing a person's ability to adapt to flood flow conditions; they will change their posture to best stabilise themselves in a flood.

Abt *et al*. (1989) found an equation for defining the threshold of instability of a person in flood flow by carrying out a linear regression on the experimental data. The r^2 value was only 0.48 so the uncertainty associated with the relationship is high. Their equation is:

$$dv = 0.0929 [e^{0.022 (2.2m + h/25.4) + 1.09}]^2$$

where dv is the product number in m^2/s, m is the person's weight in kg and h is the person's height in m.

7.4.2 RESCDAM, Helsinki University of Technology, 2000

The EU RESCDAM project was co-ordinated by the Finnish Environment Institute and focussed on the development of rescue actions based on dam-break flood analysis. They studied:

- human stability and manoeuvrability in flowing water
- permanence of houses in flowing water
- roughness coefficients of forest and houses.

The research on human stability involved flume experiments much like the Abt *et al* (1989) study. Human subjects were tested on an adjustable platform structure in a flume. The results were compared to the results from Abt *et al*. (1989) and it was found that the product numbers in the RESCDAM project were lower. The researchers explain that the difference is due to the use of different clothing and different bottom material. The survival suits used in the RESCDAM study increase buoyancy and reduce mobility. In addition, the bottom surface was more slippery in the RESCDAM study.

The RESCDAM study highlights that conditions will have an impact on the ability of a person to stand up in flowing water. Stability will be impaired under the following conditions:

- Bottom: uneven, slippery, obstacles
- Water: floating debris, low temperature, ice, poor visibility
- Human subject: additional loads, disabilities, aged
- Others: poor lighting.

The limits of human manoeuvrability are described by the following equations:

$dv = 0.006hm + 0.3$ for good conditions

$dv = 0.004hm + 0.2$ for normal conditions
$dv = 0.002hm + 0.1$ for poor conditions.

To apply the most suitable equation requires an assessment of the conditions, checking the factors listed above.

7.4.3 Keller and Mitsch (1993)

Keller and Mitsch (1993) carried out research on the stability of both cars and people in flood conditions in order to inform the design of urban streets as floodways for floods greater than around the five year return period when the underground drainage system reaches capacity. Their findings resulted in recommendations for the design of road cross sections to minimise the risk to people on the road during a flood.

The research took an entirely theoretical approach and considered the physics of vehicle and person stability in flood conditions. The analysis of vehicle stability involved calculations for three types of common cars. The analysis of person stability considered the case of an average-size five year old child with the aim of taking into account the highest risk scenario. Children have a smaller stature and so are more at risk of falling and drowning in flood waters, and children under five years old are likely to be under the control of adults at all times and therefore be less at risk than a five year old on their own.

The vehicle stability calculations were based on the distribution of the buoyancy force between the two axles. The axle load for the front and rear axle was estimated from car manufacturer specifications. Vehicle instability occurs when the drag force imposed by the flowing water at an axle is equal to the restoring force due to the axle load. The drag force acting on the side of the vehicle is a function of the density of water, the drag coefficient, the submerged area of the vehicle projected normal to the flow and the velocity of flow. The value of the drag coefficient is itself a function of depth.

The analysis of the instability of a child in a flood identified and evaluated two mechanisms of instability. Like Abt *et al.* (1989), this research analysed the toppling hazard caused by the situation where the moment of the drag force exceeds the restoring moment of the child's weight. In addition, they also considered the situation where the drag force is greater than the frictional resistance between the child's feet and the road surface.

The person toppling hazard, or 'moment' instability occurs when the flowing water exerts an overturning moment about a pivot point on the circumference of the base of a cylinder representing the child. The point of instability occurs when the overturning moment, a function of the drag force and the depth of water, is equal to the restoring moment.

The alternative mode of instability is 'friction' instability and is calculated by finding the normal force from the weight of the child and the buoyant force for each depth. The velocity at which the child becomes unstable is defined by the normal force exceeding the maximum resisting friction force.

The significance of each mechanism of instability is dependant on the depth of the water. This research finds that the 'friction' mode of instability is more severe than the 'moment' mode of instability for depths up to 0.55m, and at depths deeper than this the 'moment' mode is more severe.

7.5 Interim Report 1 Hazard rating analysis

A hazard rating relates the critical threshold of a person falling over to the conditions of the flood, which have been defined in most studies as depth and velocity, although other factors such as rate of rise and debris have been used in some expressions as well (see Asselman, N.E.M. and Jonkman, S.N., 2003; Betâmio de Almeida, A., 2001).

Table 7.1 summarises the test conditions of the Abt *et al*. and RESCDAM experiments.

Table 7.1 Test conditions of previous experiments

Ref	Standing / walking	Substrate / water conditions	Safety equipment	Test conditions	Subjects
Abt *et al*. 1989	Periodic walking	Grass, concrete, steel, gravel. Water 20-25°C.	Jeans and shirt. Harness. Helmet.	2-4 tests in 2 hrs. v 0.36-3.05 m/s, d 0.42-1.2 m.	female and male, 19-54 yrs, good health. m 41-91kg. h 1.52-1.91m
RESCDAM 2000	Periodic walking	Steel grating-fairly slippery. Water 16°C.	Gortex survival suits, helmet, safety ropes, handles.	v 0.6-2.75 m/s, d 0.3-1.1m.	female and male. m 48-100 kg. h 1.6-1.95m. 2 subjects were professional rescuers

The flumes at HR Wallingford can simulate flows 0.7 – 2 m/s and depths 0.1 – 1.2 m. This does not significantly expand the ranges that have been tested by previous experiments. Given that Abt *et al*. carried out such extensive experiments, which have been compared to the RESCDAM data, further tests are unlikely to improve the quality of data.

A theoretical assessment of human instability in flood water should analyse the forces acting on the body in water (buoyancy, hydrostatic force etc). The empirical analyses consider the relationship between height – weight and velocity – depth. They are two slightly different approaches and ongoing work will compare the difference between the results given by each and the theoretical implications of each. One of the drawbacks of the theoretical approach, as identified by Abt *et al*. (1989), is that it is very difficult to account for the effect of a person's ability to change their posture to adapt to flood flow conditions.

Abt *et al*. (1989) did not justify the product number approach for providing an empirical analysis to relate the product number to the height and weight of the subject in order to identify the point of instability of a human subject in flood flow. The product of depth and velocity may not be the most appropriate measure for assessing stability as although depth and velocity are the two factors that most affect the flow conditions a person must stand up in, taking the product may not be the best way in which to combine the two factors. The following analysis of the data from the Abt and the RESCDAM experiments also looks at v^2 and d(v+1.5). There is a theoretical rationale for each approach. Using v^2 takes into account the potential danger of debris as it accounts for shear stress, which is one of the main influencing factors on debris potential in a flood. A constant is added to v so that deaths can still occur if there is no velocity, reasoning that was developed in Flood Risks to People Phase 1. Furthermore, people will drown in deep water, whether it is fast flowing or not, and also damage will occur to buildings in deep water as a result of water pressures and floating debris.

The Flood Risks to People Phase 1 report also proposed that a simple debris factor be added to the index in order to account for the impact of debris on the risk to people in a flood. When applying a debris factor, it should not be included in order to account for its influence in increasing depth and velocity because this is already taken into account with depth and velocity in the equation. The debris factor must be used, therefore, on the basis that the debris itself has potential to be a risk to people. The magnitude of the debris factor must be devised with reference to the magnitude of values resulting from the depth-velocity function. This ensures that the combined expression gives appropriate weight to the relative influence of depth, velocity and debris.

The debris factor must take into account both the quantity (or severity) of the debris and the probability that the given quantity of debris will occur. The quantity of debris should be taken into account with a simple factor, so that the overall debris factor is calculated as:

Debris factor = quantity factor x probability

The debris factor may increase as the velocity or depth increases as rougher flow conditions will cause an increase in damage to buildings, infrastructure and trees, and hence there will be more debris. The debris factor will be a function of the flood and of the nature of the area where the flood occurs (i.e. potential for debris).

The Abt data and the RESCDAM data have been analysed for relationships describing the critical depth and velocity thresholds for a person of a given height and weight. The Abt data has been analysed by averaging the depth and velocity results for each subject under all surface type conditions for the lower slope of 0.005 (since this lower slope is more comparable with the zero slope of the RESCDAM experiments). The RESCDAM data has been analysed by averaging the depth and velocity results for each subject (all other conditions being constant). These two sets of averaged data were analysed separately and together to give the resulting equations listed in Table 7.2.

Table 7.2 Velocity – depth relationships

x	y	Critical threshold for loss of stability	r^2
Equations based on Abt data			
hm	dv	y = 0.0069x + 0.0615	0.6980
hm	dv^2	y = 0.0198x - 0.1184	0.4812
hm	d(v+1.5)	y = 0.0094x + 1.7517	0.5271
Equations based on RESCDAM data			
hm	dv	y = 0.0044x + 0.473	0.8528
hm	dv^2	y = 0.0128x – 0.2228	0.6792
hm	d(v+1.5)	y = 0.0031x + 1.8492	0.2537
Equations based on combined data			
hm	dv	y = 0.0064x + 0.4466	0.3383
hm	dv^2	y = 0.0174x – 0.3202	0.3809
hm	d(v+1.5)	y = 0.0072x + 1.6795	0.2147

where h = height (m), m = mass (kg), v = velocity (m/s), d = depth (m)

Table 7.2 shows that when the data from the two experiments is analysed separately, the equations with the strongest correlation are those relating the height and weight of a person to the product number (dv) rather than to dv^2 or to d(v+1.5). The correlation for the equation derived from the RESCDAM data is stronger than for the equation for the Abt data. When the two sets of data are combined, the relationships are weaker because there is high scatter in the data, indicating two separate relationships, see Figure 7.1.

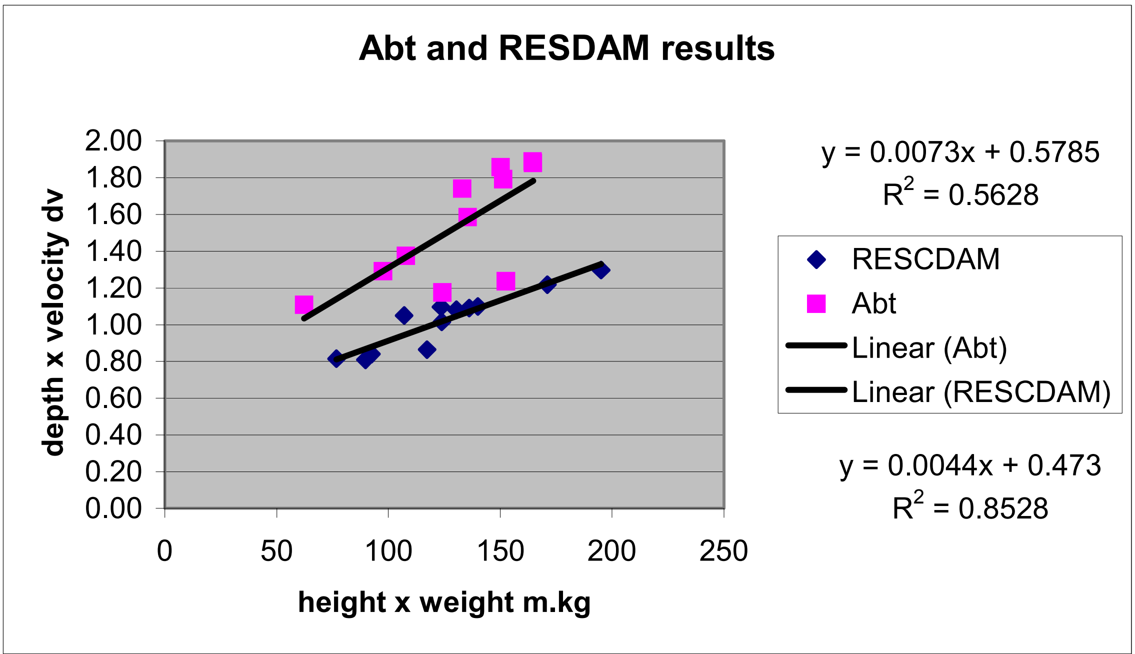


Figure 7.1 Graph showing the two separate data sets from Abt and RESCDAM

The student's t test shows that the two data sets are statistically significantly different and cannot be considered to be from the same population. This reflects the fact that the two experiments were carried out under slightly different conditions and therefore the data should not be combined for analysis. Instead, the different conditions that have been tested can give an indication of the stability of a person in different conditions of flood water. The RESCDAM study identified that the threshold for a person falling over would change according to other factors as well as velocity and depth and gave three different equations for the critical threshold depending on whether the conditions were poor, normal or good. Their equations assume that as the conditions of the flood get worse, the y intercept and the gradient of the straight line relationship both decrease. This appears to be justified by the data, presented in Figure 7.1, where the Abt data, collected in better conditions than the RESCDAM data, has a steeper slope and a higher intercept. This can also be seen in Figures 7.2 and 7.3, where the relationship developed from the steeper slope of 0.015 compared to 0.005 gives lower product numbers.

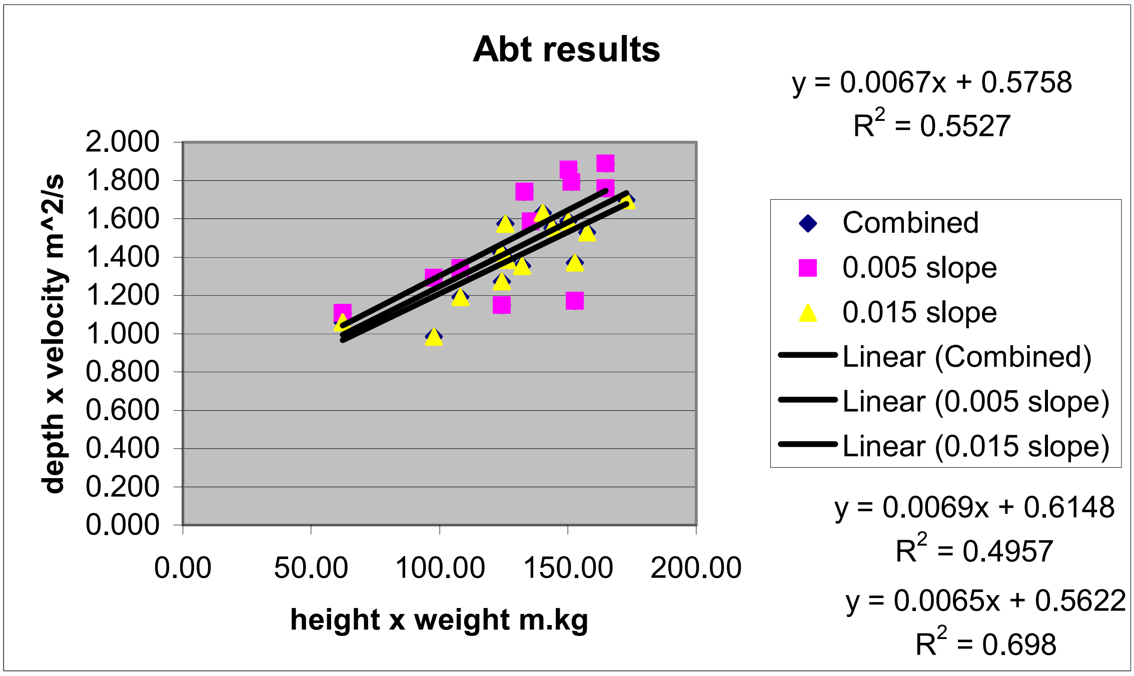


Figure 7.2 Abt data, dv relatiosnhips

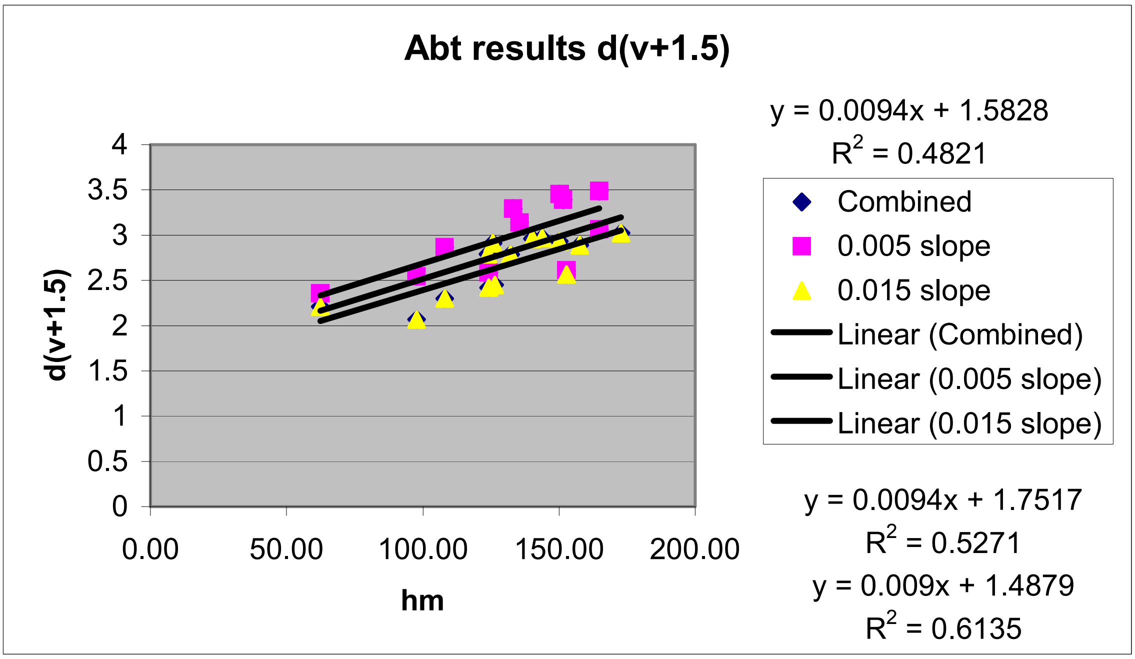


Figure 7.3 Abt data, d(v+1.5) relationships

From this analysis, we see that the stability of a person in water depends on the height and weight of a person. For the purposes of identifying the hazard rating of an area in order to map the hazard, it is necessary to make more general statements about the hazard that particular flood characteristics present to the entire population within that area. This allows a map to show areas of different hazard categories that are "dangerous for some", "dangerous for most" or "dangerous for all". To do this, the hazard rating equation [(v+1.5) x d] is applied to the data from the Abt and RESCDAM experiments. The class boundaries defining the three hazard categories are found by finding the 50^{th} and 100^{th} percentiles of the figures given by the hazard rating. This defines the hazard categories as:

<0 percentile: not dangerous
0-50^{th} percentile: dangerous for some
>50^{th} – 100^{th} percentile: dangerous for most
>100^{th} percentile: dangerous for all

So, the threshold for the value of [(v+1.5) x d] where 100% of the sample from the Abt and RESCDAM experiments defines the point at which the flood presents a hazard to the entire population of a floodplain.

Tables 7.3 and 7.4 show the thresholds of the three hazard categories for different combinations of depth and velocity. This gives an indication of the bands of risk to people. Table 7.5 shows the estimated percentiles for the proportion of the population that are injured or killed in a flood with various velocity – depth combinations.

Table 7.3 Hazard classification table with thresholds based on Abt data

(V+1.5) * D

Velocity	Depth 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	With thresholds based on Abt									
0.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
0.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
1.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
1.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
2.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
2.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
3.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
3.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
4.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75
4.50	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00
5.00	1.63	3.25	4.88	6.50	8.13	9.75	11.38	13.00	14.63	16.25

Based on Abt	From	To	
Class 1	1.48	2.64	Danger for some
Class 2	2.64	3.53	Danger for most
Class 3	3.53	20.00	Danger for all

Table 7.4 Hazard classification table with thresholds based on Abt and RESCDAM data combined

(V+1.5) * D

Velocity	Depth 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	With thresholds based on Abt and RESCDAM									
0.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
0.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
1.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
1.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
2.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
2.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
3.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
3.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
4.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75
4.50	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00
5.00	1.63	3.25	4.88	6.50	8.13	9.75	11.38	13.00	14.63	16.25

	From	To	
Class 1	1.00	2.00	Danger for some
Class 2	2.00	3.00	Danger for most
Class 3	3.00	20.00	Danger for all

Table 7.5 Table of percentiles of population at risk for given depth – velocity conditions

HRW Scoping Study
Fatality Rate 2 * HR

(V+1.5) * D

Velocity	Depth 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	With thresholds reduced + debris factor							0.50		
0.00	1%	2%	2%	3%	4%	5%	5%	6%	7%	8%
0.50	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1.00	1%	3%	4%	5%	6%	8%	9%	10%	11%	13%
1.50	2%	3%	5%	6%	8%	9%	11%	12%	14%	15%
2.00	2%	4%	5%	7%	9%	11%	12%	14%	16%	18%
2.50	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%
3.00	2%	5%	7%	9%	11%	14%	16%	18%	20%	23%
3.50	3%	5%	8%	10%	13%	15%	18%	20%	23%	25%
4.00	3%	6%	8%	11%	14%	17%	19%	22%	25%	28%
4.50	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%
5.00	3%	7%	10%	13%	16%	20%	23%	26%	29%	33%

By taking this approach, we presume that the subjects used in the physical experiments are representative of the population in the floodplain. Although there are a range of subjects from both the Abt and RESCDAM experiments, this is obviously a limitation with using the empirical data. The diagrams do, however, show how the flood characteristics relates to the risk to people.

7.6 Interim Report 2 Hazard Rating Analysis

Background

The main body of research on flood hazard rating was reported in Interim Report 1. In this section some further discussion and interpretation is presented to address some outstanding issues and respond to comments made through consultation.

In Phase 1 of the Risks to People project the following flood hazard formula was proposed:

Flood hazard = d . (v +1.5) + DF

Where:

d is depth m
v is velocity ms^{-1}
DF is a debris factor with a value of 0, 1 or 2

This formula provided a pragmatic solution to the estimation of hazard. The coefficient of "+1.5" ensured that the flood hazard did not reduce to zero when velocity was zero and the debris factor reflected the additional hazard presented by floating objects that could increase the chance of falling or toppling in flood water. The overall phase 1 method was tested for three case studies and produced good estimates of the number of people killed or harmed in each flood event.

In Interim Report 1, a more detailed analysis of flood hazard ratings was presented based on experimental data from Colorado State University (Abt, 1989) and Helsinki University (RESCDAM, 2000). This showed that the simple product of depth times velocity appeared to fit the data far better than the Phase 1 flood hazard formula. Three different formulae were compared but it was argued that the empirical evidence was not sufficient to warrant any change in the Phase 1 approach.

Options for final flood hazard formula

In this report we have revisited the analysis to consider the following options:-

1) Reducing the coefficient from "+1.5" to "+0.5"[5]
2) Reducing the range of the debris factor from 0-1 rather than 0-2
3) Selecting flood hazard thresholds that will inform Environment Agency guidance

Reducing the velocity coefficient

The first option of using a formula "d x (v +0.5) + DF" provides a compromise between the pragmatic approach and providing a formula with an improved fit to the experimental data. As such, it would be more defensible when flood hazard information is used to support decisions, e.g. regarding the delineation of flood warning areas or location of new development.

[5] The final choice of formula (or formulae) will be made in the final stage on "refinement of the methodology" and will be discussed at the Project Board meeting in November 2004.

Figure 7.4 shows the "averaged" experimental data from Abt (1989) and Rescdam (2000). Two outliers from the Abt data set were removed. The y-axis uses the proposed formula that fits the data well with regression coefficients of x and y compared to a fit of a and b with Phase 1 formula (see Table 3.3, IR1. HR Wallingford, 2004b).

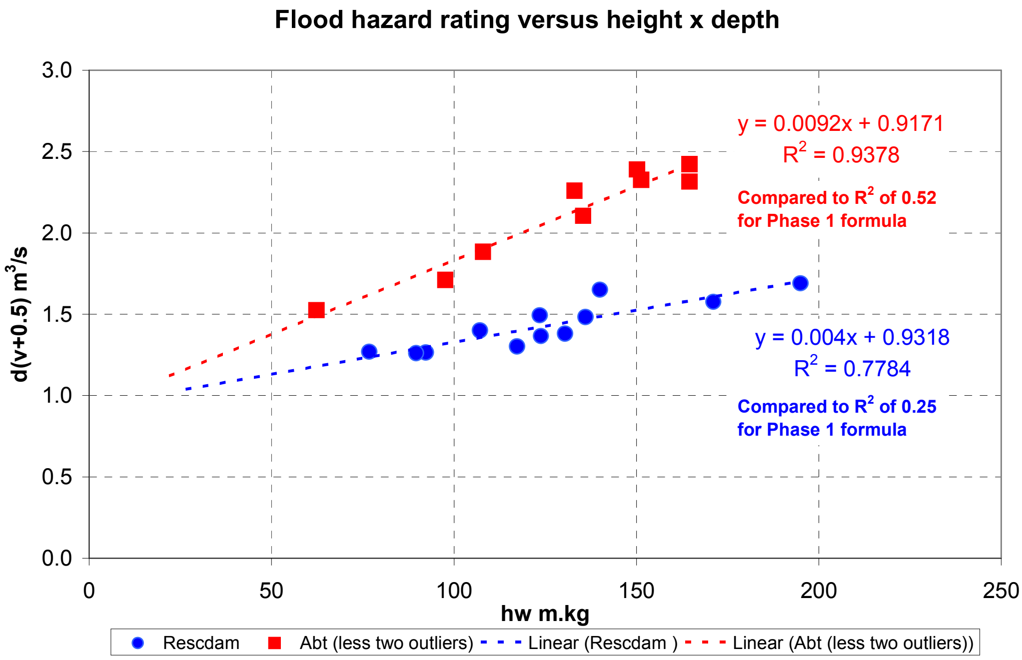


Figure 7.4 Experimental data from Abt (1989) and Rescdam (2000) against a revised flood hazard formula

Reducing the debris factor

There is very little information on the impact of debris on flood hazard and further consideration of this factor and how it can be mapped is required in as part of the refinement of the methodology. At present it has a large impact on the flood hazard rating and within the overall methodology is the 5th most important factor above the area vulnerability variables. Secondly, it will be difficult to derive a debris factor score and therefore it may be a major source of uncertainty in the overall method. On balance a scale of 0, 0.5, 1 may be more proportionate that 0, 1, 2.

Table 7.6 The relative importance of individual factors in the Phase 1 method considering different flood hazard formulae

Rank order	Phase 1 method	d*v	d*v^2
#1	Depth	Depth	Velocity
#2	The very old	Velocity	Depth
#3	Infirm/disabled/sick	The very old	The very old
#4	Velocity	Infirm/disabled/sick	Infirm/disabled/sick
#5	Debris	Debris	Debris
#6 =	Flood warning	Flood warning	Flood warning
	Nature of area	Nature of area	Nature of area
	Speed of onset	Speed of onset	Speed of onset

People vulnerability
Area
Flood hazard

Selection of flood hazard thresholds for guidance

One output of the project will be guidance on the relative danger of different flood hazards. Our approach in IR1 of describing flood hazard as "dangerous for some", "dangerous for most" and "dangerous for all" is appropriate although the final classes may need to be named using more standard risk terminology. It is impossible to quantify the impact of flood hazard more precisely due to the large variation in the chance of toppling or falling due to age, height, mass, fitness, experience, ground conditions, clothing and so on. Nevertheless it is important to choose any threshold carefully and reinforce the message that dry access and exit routes are always preferable and that people should stay out of floodwater.

Figure 7.5 reproduces experimental data from the previous figure but also shows the average height times mass of UK population based on Department of Health figures and identifies some potential thresholds for flood hazard classes. It can be seen that the people involved in the experiments were in the height and weight range of teenagers to tall or heavy adults and that the fitted equations need to be extrapolated into the height and mass range of younger children. If this extrapolation is used directly it suggests that a lower "d.(v+0.5)" "dangerous for some" threshold of 1.0 may be appropriate. This would be equivalent to the following scenarios with a debris factor of zero:-

- 66 cm depth moving at 1 ms^{-1}
- 1m depth moving at 0.5 ms^{-1} or, in the extreme case,
- 2m of still water

All these cases still appear hazardous, particularly the latter which would be equivalent to being out of your depth in a swimming pool. Therefore a lower threshold would be more appropriate, possibly of 0.75 for the lower margin of the *"dangerous for some"* class.

In all cases of flooding, except groundwater flooding, a debris factor would also be added, e.g. if the debris factor was just 0.5 a threshold of 0.75 would be equivalent to a flood with a depth of 0.5m and zero velocity:-

Flood hazard = d.(v+0.5) + DF
= 0.5 * 0.5 + 0.5
= 0.75

For the "*dangerous for some*" class, a conservative upper threshold of 1.5 is suggested which is a fairly central value in the Rescdam data set. A maximum "*dangerous for all*" threshold could take a similarly conservative view of using the Rescdam data but as this is clearly not the case a higher threshold is suggested of "d x (v+0.5) + DF" equal to 2.5.

Therefore the following thresholds are proposed:-

Flood hazard d.(v+0.5) + DF	Description	Alternative name/hazard class
0	Safe (dry)	None
0 – 0.75	Caution	Low
0.75 to 1.5	Dangerous for some	Moderate
1.5 to 2.5	Dangerous for most	Significant
Over 2.5	Dangerous for all	Extreme

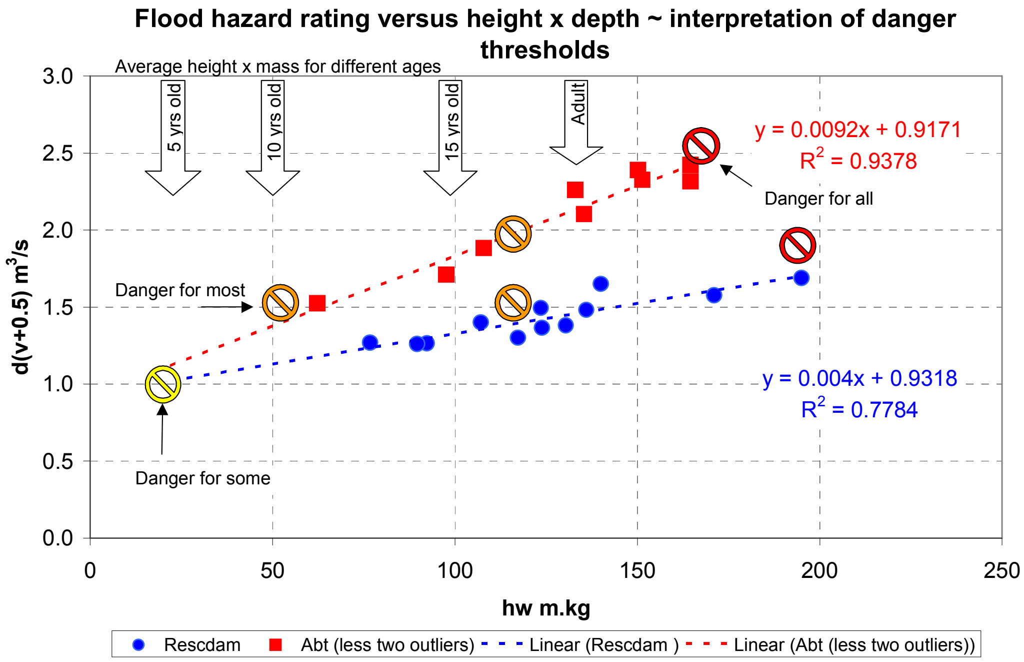


Figure 7.5 Experimental data and potential flood hazard thresholds

7.7 Flood hazard matrix for risks to people

Table 7.7 shows flood hazard matrices for situations with a debris factor of zero, 0.5 and 1, based on the formula and thresholds proposed in Section 7.6.

Table 7.7 Flood hazard ratings for floods with a debris factor equal to (a) zero, (b) 0.5 and (c) 1

(a)

d * (v+0.5) + DF

Velocity	Depth 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25
0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75

	From	To	
Class 1	0.75	1.50	Danger for some
Class 2	1.50	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

(b)

d * (v+0.5) + DF

Depth 0.50

Velocity	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	0.63	0.75	0.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75
0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
1.00	0.88	1.25	1.63	2.00	2.38	2.75	3.13	3.50	3.88	4.25
1.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50
2.00	1.13	1.75	2.38	3.00	3.63	4.25	4.88	5.50	6.13	6.75
2.50	1.25	2.00	2.75	3.50	4.25	5.00	5.75	6.50	7.25	8.00
3.00	1.38	2.25	3.13	4.00	4.88	5.75	6.63	7.50	8.38	9.25
3.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50
4.00	1.63	2.75	3.88	5.00	6.13	7.25	8.38	9.50	10.63	11.75
4.50	1.75	3.00	4.25	5.50	6.75	8.00	9.25	10.50	11.75	13.00
5.00	1.88	3.25	4.63	6.00	7.38	8.75	10.13	11.50	12.88	14.25

	From	To	
Class 1	0.75	1.50	Danger for some
Class 2	1.50	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

(c)

d * (v+0.5) + DF

Depth **With thresholds reduced + debris factor** 1.00

Velocity	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	1.38	1.75	2.13	2.50	2.88	3.25	3.63	4.00	4.38	4.75
0.50	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00
1.00	1.63	2.25	2.88	3.50	4.13	4.75	5.38	6.00	6.63	7.25
1.50	1.75	2.50	3.25	4.00	4.75	5.50	6.25	7.00	7.75	8.50
2.00	1.88	2.75	3.63	4.50	5.38	6.25	7.13	8.00	8.88	9.75
2.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00
3.00	2.13	3.25	4.38	5.50	6.63	7.75	8.88	10.00	11.13	12.25
3.50	2.25	3.50	4.75	6.00	7.25	8.50	9.75	11.00	12.25	13.50
4.00	2.38	3.75	5.13	6.50	7.88	9.25	10.63	12.00	13.38	14.75
4.50	2.50	4.00	5.50	7.00	8.50	10.00	11.50	13.00	14.50	16.00
5.00	2.63	4.25	5.88	7.50	9.13	10.75	12.38	14.00	15.63	17.25

	From	To	
Class 1	0.75	1.50	Danger for some
Class 2	1.50	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

7.8 Flood hazard matrix for vehicles

Background

Experience from past floods, particularly in the United States, shows that a common hazard that causes a risk of death or serious injury to people is the instability of vehicles in the floodwater. This hazard presents a number of potential consequences. The primary consequence is the injury or death of a person resulting from them being trapped in the vehicle when it loses stability. The likelihood of this occurring relates to the behaviour of that person, since it is often the case that people underestimate the velocity or depth of the floodwater and attempt to drive through it when it is in fact unsafe. If the person is trapped in a vehicle in floodwater they are vulnerable to a range of risks e.g. drowning and injury or death caused by debris impact on the vehicle or the vehicle crashing into a structure.

It is useful to attempt to characterise the stability thresholds of a vehicle in water in a similar way to how the stability of people is presented in order to provide general guidance for evacuation plans. However the hazards presented by being trapped in vehicles will not form part of the final mapping methodology.

Flood hazard calculation

The analysis of Keller and Mitsch (1993) provides a simple method for estimating the forces exerted on a stationary vehicle in floodwater. The method considers vehicle mass and dimensions, buoyancy and drag forces and can be used to determine the velocity of water required to make a vehicle unstable at low depths and also the depth at which a "water-tight" vehicle would float. The results produced from these calculations are subject to several caveats:-

- The method does not consider hydrostatic pressures of water on the upstream face of the vehicle that may make it unstable at lower velocities.
- Forward momentum is not considered and when vehicles are driving at speed they could "lose grip" and "aquaplane" at much lower depths and velocities.
- The volume displaced by a vehicle and consequently the buoyancy force may be lower as we have assumed that the wheels and the chassis form a solid volume.

The calculation process follows the steps below:

- Calculation of the buoyancy force, B_f in kilograms.

$$B_f = \rho L A$$

where ρ is the density of water, L is the submerged depth and A is the vehicle plan area.

- Calculation of the axle load in wet conditions, found from summing the buoyancy force and the axle load in dry conditions.
- Calculation of the Restoring force at the axle, F_r.

$$F_r = \mu \text{ (wet axle load)}$$

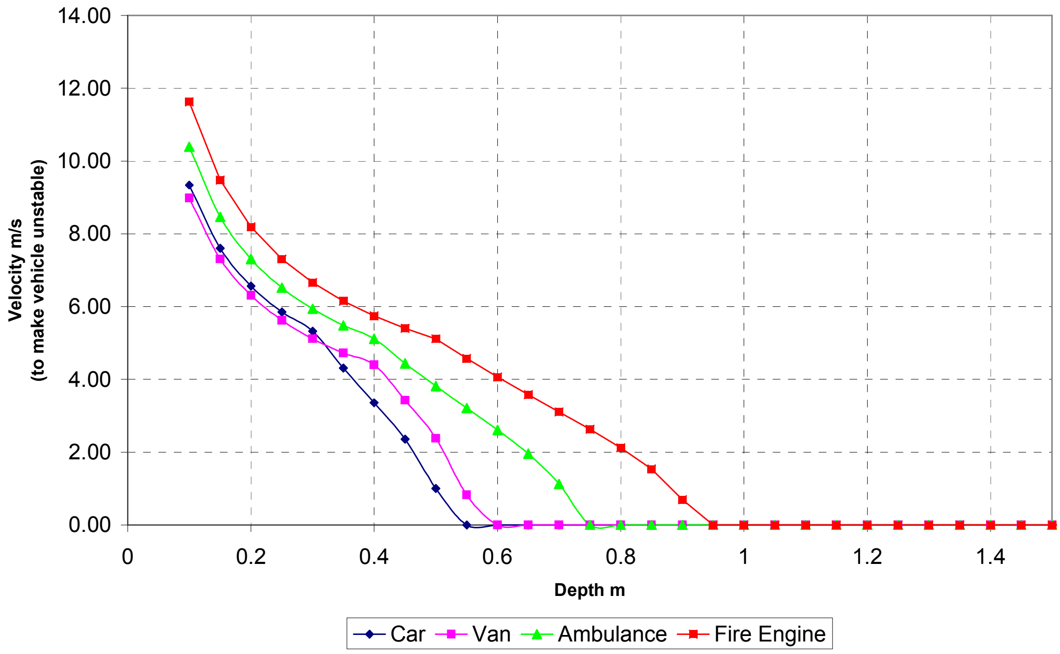
where μ is the friction coefficient, set at 0.3 after Bonham and Hattersley (1973) in Keller and Mitsch (1993).

- Calculation of the velocity at which the vehicle will become unstable, V.

$$V = 2\,[F_r / (\rho\, C_D\, A)]^{1/2}$$

where C_D is the drag coefficient, set at 1.1 if the water level is below the chassis and 1.15 if the water level is above the chassis (after Gerhardt et al. (1992) in Keller and Mitsch (1993)).

Figure 7.6 shows the instability of a standard saloon car, van, ambulance and fire engine. As depth increases the velocity required to make a vehicle unstable decreases because the downward force of the vehicle is countered by increased buoyancy. When flood depth is greater than the chassis height a larger amount of water is displaced and stationary vehicles will float at fairly shallow depths between 50 and 100 cm. At this stage the assumptions regarding vehicle weight have been researched but other assumptions regarding exact chassis heights and the amount of water displaced by tyres are estimates, so the figures should be regarded as draft.



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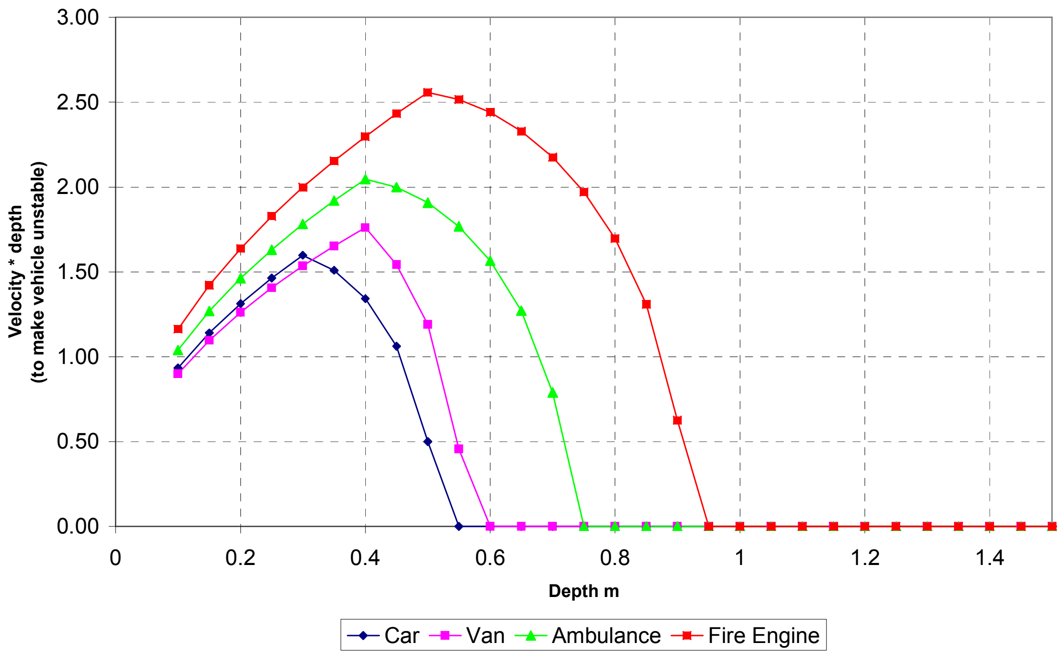

Figure 7.6 Flood hazards for different vehicles. (a) Critical velocities versus depth and (b) Flood hazard (v * d) versus depth.

Table 7.8 presents an example flood hazard matrix for a saloon car using the same velocity depth increments as the people vulnerability matrix. It is clear the vehicles are more vulnerable than people in deeper floodwater.

Table 7.8 Flood hazard matrix for saloon car (Peuguot 307)

Velocity \ Depth	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	s	s	floats	floats	floats	floats	floats	floats	floats	floats
0.50	s	s	floats	floats	floats	floats	floats	floats	floats	floats
1.00	s	s	floats	floats	floats	floats	floats	floats	floats	floats
1.50	s	u	floats	floats	floats	floats	floats	floats	floats	floats
2.00	s	u	floats	floats	floats	floats	floats	floats	floats	floats
2.50	s	u	floats	floats	floats	floats	floats	floats	floats	floats
3.00	s	u	floats	floats	floats	floats	floats	floats	floats	floats
3.50	s	u	floats	floats	floats	floats	floats	floats	floats	floats
4.00	s	u	floats	floats	floats	floats	floats	floats	floats	floats
4.50	s	u	floats	floats	floats	floats	floats	floats	floats	floats
5.00	s	u	floats	floats	floats	floats	floats	floats	floats	floats

Note; s= stable, u= unstable

This research on vehicles will inform guidance and may also be used to refine aspects of Area Vulnerability as the presence of major transport links within the floodplain will increase the chance of exposure to flooding.

7.9 Flood hazard matrix for buildings

Background

Floodwater pressure on a building is made up of several components. The three main flood actions are (from Kelman, 2004):

1. Water contact: correlates property damage with flood depth
2. Depth differential between water levels outside and inside of property
3. Velocity pressure on property walls

This means there is therefore an extra factor determining the risk to damage to a building when compared to the risk of loss of stability of a person or a vehicle. In addition to the depth and velocity of the floodwater, it is also important to assess the depth differential of the floodwater.

Kelman (2002) proposes matrices for damage to buildings based on the maximum flood depth differential and the maximum flood velocity. Five potential levels of damage are assigned to different depth differential/velocity combinations, from minor water contact and infiltration to irreparable structural damage. The matrices are produced for buildings with different foot print areas and different numbers of storeys. The resulting matrix is therefore dependent on the type of property and will be different for a residential house compared to a multi-storey office block. The specification of the depth differential assumes that there is no depth inside the building, so the matrices take into account the actual floodwater depth.

Matrix for buildings

In detailed calculations of building vulnerability, it is important to take into account the building parameters that will have an effect on the impacts it will suffer during a flood (such as the footprint and the number of storeys; the principal components as determined by Kelman (2002)). However, for Flood Risks to People Phase 2 the aim is to give an overview of the flood conditions that will cause damage to buildings that may inform guidance from this or other related projects. Therefore an analysis has been carried out by considering the vulnerability profiles for each of Kelman's (2002) twelve examples together. The twelve profiles cover buildings of different footprint areas and storeys, from bungalows to four storey apartment blocks.

The analysis for Flood Risks to People Phase 2 has taken an average of Kelman's (2002) damage scale for each building type in each depth differential-velocity combination of the matrices. The five damage scales have been simplified into three damage categories. The resulting matrix, presented in Figure 7.7, is an indicative assessment of the damage that will occur to buildings on the floodplain in different depth differential/velocity combinations. The matrix is a preliminary assessment and more detailed analysis should be carried out to determine specific damage to individual buildings if necessary, that takes into account the building parameters.

	depth differential (m)				
velocity (m/s)	0	0.5	1	1.5	2+
0	0	2	3	4.3	4.8
0.5	0	2	3.6	4.4	4.8
1	0	2	3.6	4.4	4.8
1.5	0	2.5	3.6	4.5	4.8
2	0	2.5	4.2	4.5	4.9
2.5	0	2.5	4.2	4.7	4.9
3	0	2.5	4.3	4.8	5
3.5	0	3	4.3	4.8	5
4	0	3	4.5	4.9	5
4.5	0	3.6	4.5	4.9	5
5	0	3.6	4.8	5	5
5.5	0	4.2	4.8	5	5
6	0	4.2	5	5	5
6.5	0	4.3	5	5	5
7	0	4.3	5	5	5
7.5	0	4.4	5	5	5

	From	To	
Class 1	1	3	some damage
Class 2	3	5	severe damage
Class 3	5	5	irreperable damage

Figure 7.7 Flood risk to buildings matrix

This research will be considered in the next stages for setting classes of area vulnerability based on the types of property present.

7.10 Estimating flood hazards due to breach and overtopping

One issue that arose during the consultation was the requirement to derive hazard ratings behind existing or proposed on line defences.

Some preliminary work was completed to develop flood hazard curves behind defences as a function of water head and distance from the defence. These curves are required for areas where there are no detailed hydraulic models available.

The example curves in Figures 7.8 and 7.9 are based on modelling an idealised floodplain using the 2D LisFLOOD model (the area modelled was 10 x 10 Km^2 with a mild slope of $5x10^{-5}$ and a 50 m grid size). The hazard rating equation used was:

(v + 1.5) x d

as described in Section 6.5 of this report. Both the overtopping and the breach scenarios show a very high initial hazard for the first 100 m, approximately 3 to 4 times greater than the threshold values that would knock over the most fit and experienced person. The flood hazard for the breach scenario reduces quickly as the flood wave dissipates laterally and is stored in the floodplain area. The decay of flood hazard is slower for the overtopping scenario.

By comparing the velocity-depth thresholds discussed in Section 7.5 with the graphs it can be seen that different parts of the floodplain fall into different hazard categories – “dangerous for some”, “dangerous for most”, “dangerous for all” and so on. Treating the floodplain extent as a single risk zone will misrepresent the risks to people.

Another interesting preliminary conclusion from this work is that the decay functions follow a similar shape. It may be possible to develop simplified general function of flood hazard versus distance that would be useful for GIS mapping.

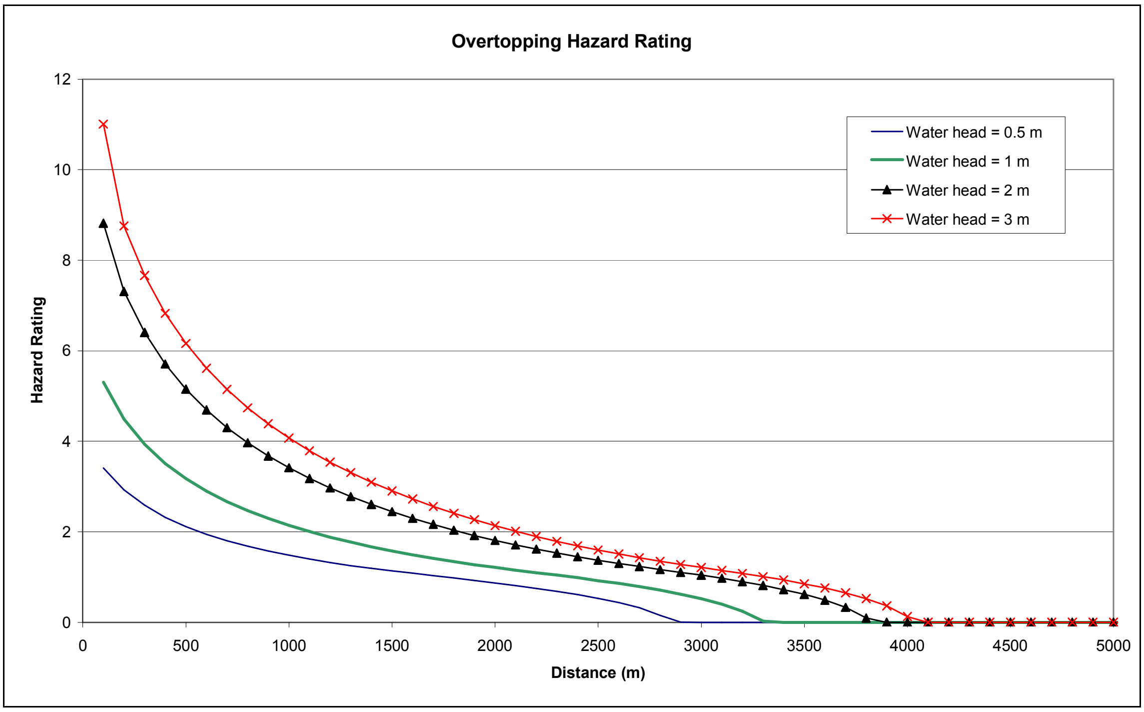

Figure 7.8 Overtopping hazard rating vs water head and distance from the on line defence (water head is the head above the on line defence where overtopping occurs)

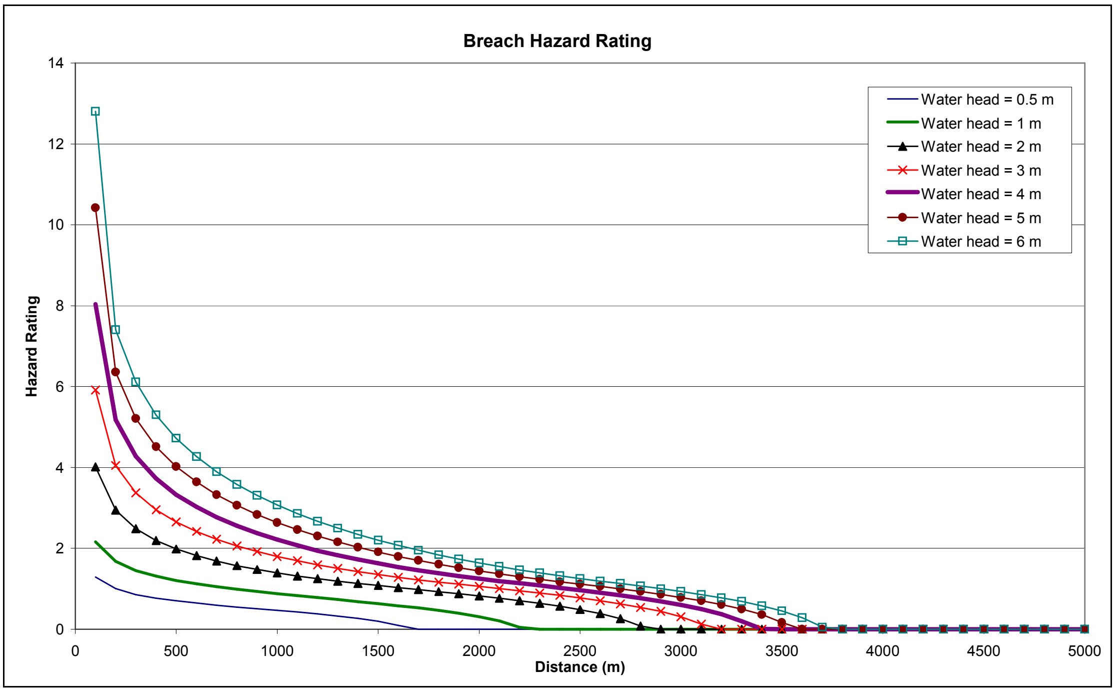

Figure 7.9 Breach hazard rating vs water head and distance from the on line defence (water head is the head above the invert of the breach)

7.11 Flood hazard behind defences

Background

The nature of flood hazard behind defences is a critical issue both for the development of guidance and the mapping methodology required at the end of the project. In general terms flood velocities will be greatest directly behind defences, therefore flood hazard is higher and the individual or societal risks are greatest when people live immediately behind defences. Existing flood maps, such as the Indicative Floodplain Map and "Flood Zones" provide flood extents without flood defences and the detailed 2-D modelling required to estimate velocities and depths for a range of breach or overtopping scenarios is rarely available. In IR1 we provided some general flood hazard curves based on the 2-D Lisflood model. These illustrated how the hazard would decay behind defences as a function of the head of water, for overtopping and breach situations. As part of more recent work, similar curves have been produced using a more appropriate 2-D model called TuFlow and sensitivity tests have been completed to characterise how hazards would vary for different embayment characteristics.

Example calculations

The following assumptions were made in the following example calculations:

- The area of the floodplain was assumed to be 10 x 10 km^2 with a mild slope of $5x10^{-5}$ away from the defence and a 50 m grid size.
- The overtopping width was assumed to equal 1km of the defence length.
- For the breach scenarios, the breach width was assumed to equal 100 m of the defence length.

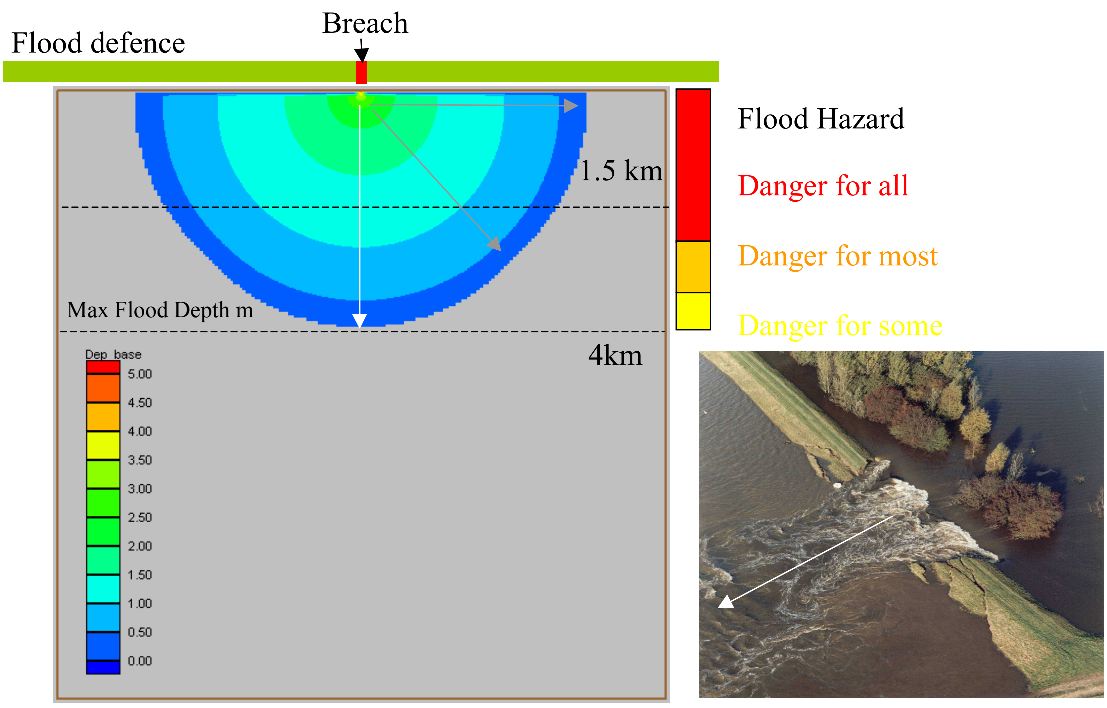

Figure 7.10 Schematic showing the model set up and flood depths following a breach

Maximum depth and velocity were obtained from TUFLOW for each grid cell and the hazard rating was estimated using the d(v+0.5) and dv^2 equations. For each scenario the hazard rating at different distances perpendicular to the defence were plotted to show the variation of the hazard rating with the distance.

Figure 7.11 shows the decay of flood hazard perpendicular to the flood defence (the white line in Figure 7.10). When combined with thresholds of flood hazard for people the curves could provide useful guidance on the relative hazard behind defences. Before a full set of curves is developed, we need to gather some further information on embayment characteristics, consider the processes for flood hazard mapping and the potential links with the RASP system.

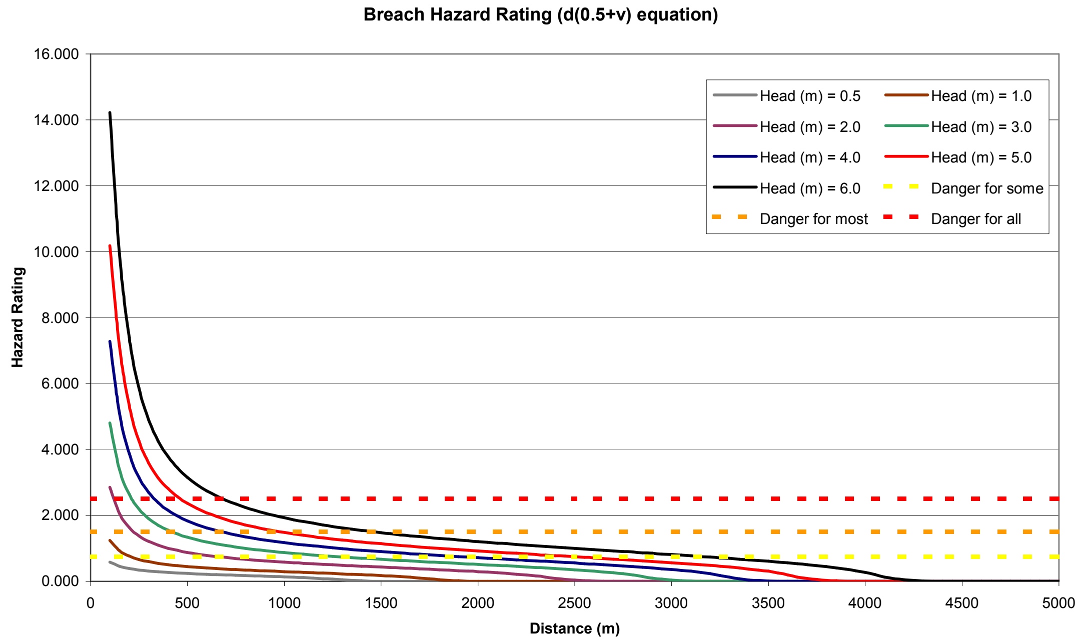

Figure 7.11 Distance decay of flood hazard behind defences

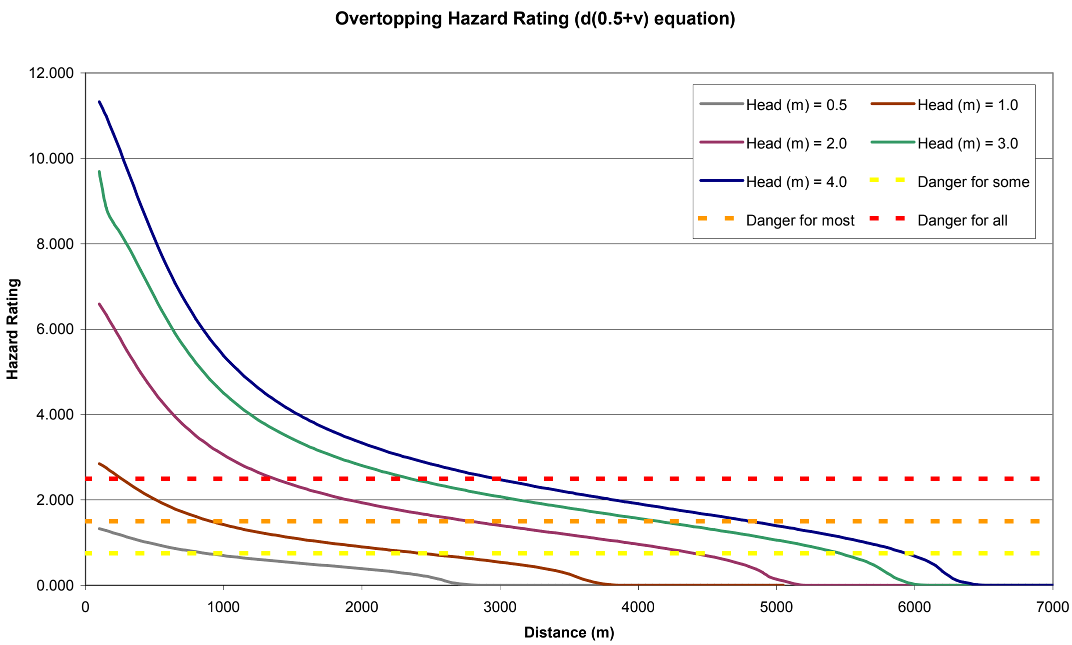

Figure 7.12 Distance decay of flood hazard behind defences

7.12 Accounting for the impacts of violent waves

The risks of violent waves overtopping sea walls were discussed in the Phase 1 report (Section 8.4). Every year there are one of more deaths caused by people being washed into the sea by wave action. Risks are greatest where there are vertical sea walls fronting pedestrian promenades, roads or railways.

Recent work by HR Wallingford (Allsop *et al.*, 2004) has developed methods for predicting the risks posed by violent waves. The data required, such as defence characteristics, sea levels and wave heights, to calculate “wave hazards” forms part of ongoing development of the RASP system. For this project we propose to include wave hazards using a simple approach of buffering the coastal defence and where this a significant risk we will provide a more detailed methodology for local assessment.

7.13 Conclusions

- The empirical evidence shows that the instability of a person in flood water is related to the height and weight of the person. Across the full range of heights and weights, the thresholds of instability are dependant on other conditions such as the clothing of the person and the bottom surface of the ground they are walking on.

- The three functions of depth and velocity have been investigated. These are vd, (v+1.5) x d and v^2d. The correlation of the height and weight of the subjects from physical testing with the functions of depth and velocity is generally not strong. The scatter in the data means that the empirical evidence alone does not support one approach over another. There are arguments for each approach but there is no reason, at this stage, to change the method from that stated in the Flood Risks to People Phase 1 report. The use of (v+1.5) x d will be reviewed again in light of the refinement of the overall methodology that is being carried out in the hazard rating refinement stage.

- Thresholds for hazard rating are shown in tables 7.3 and 7.4. These provide an indicative guide to the hazard presented by different velocity – depth combinations.

- The theoretical analysis of instability of people in flood water shows that there are two mechanisms of falling over. These are friction instability and moment instability. There has been theoretical work carried out on the risk to people in vehicles. The review of this factor will be reconsidered and enhanced with the further analysis of the behaviour dimension of the risk index.

- Previous work that has considered building collapse (Asselman and Jonkman, 2003) has been reviewed and the impact of this on the Flood Risk to People methodology will be considered in the review and enhancement of the overall method.

- A method for taking into account the occurrence of debris in a flood and its associated impact on risk to people has been proposed. The refinement of the quantity factor and methodology for estimating the probability must be investigated in the hazard rating refinement.

- The breach and overtopping hazard behind on line defences has been considered using general equations that can be applied where there is no detailed modelling of the physical situation. Relationships are developed to find the hazard rating as a function of water head and distance from the on line defence. The relationships are based on results from LisFLOOD modelling of an idealised floodplain, so to be applied elsewhere it presumes that the case has similar floodplain characteristics (size, topography, roughness) as the modelled floodplain.

- The risk to people from the violent wave overtopping hazard at coastal defences should be considered where appropriate. In the locations where this phenomenon presents a hazard, it is important to highlight this as an issue since it is a significant risk where it occurs and can be avoided easily by closing promenades and roads close to the defence if conditions approach a dangerous level. The hazard can be considered using a simple methodology where a buffer is applied to lengths of coast to highlight hot spots for violent wave overtopping where the combination of defence structure type and tide and wave conditions create a problem. Alternatively, a more detailed methodology could model the physics of the phenomena at various levels of sophistication. More detailed modelling would use information from RASP and would be based on theory developed and investigated by Allsop *et al.* (2004).

8. AREA VULNERABILITY

8.1 Introduction

In Phase 2 of this project research into Area Vulnerability has focused on (a) specific measures that can influence risks to people and (b) the risks associated with flooding and pollution.

Within a flood risk area, there are a number of measures which can influence risk to people, including:

- measures to limit the number of people at risk within the floodplain - with particular reference to land-use planning controls
- measures to limit the likelihood of flooding within the floodplain - with particular reference to the construction and maintenance of flood defences
- measures to limit the consequences of flooding within the floodplain - with particular reference to flood warning and taking appropriate evasive action in the event of a flood.

In practice, such measures are implemented through a range of actions at both national and local levels. In the sub-sections that follow, further details of these actions and associated administrative structures are presented. Particular attention is given to flood warning and its effectiveness as this is often regarded as a key factor in reducing flood risks to people (and to property). In addition, consideration is also given to whether the presence of a range of industrial facilities is likely to significantly increase risks to people in the event of flooding.

8.2 Land-use planning controls

8.2.1 Overview

As indicated above, planning controls can limit the number of people at risk within the floodplain. In practice, planning matters are dealt with by local (and regional) planning authorities with advice on flood risk provided by the Environment Agency.

A schematic overview is presented in Figure 8.1 (overleaf) with further detail provided in the text below.

8.2.2 Key players

Office of the Deputy Prime Minister

The responsibilities of the Office of the Deputy Prime Minister (ODPM) include planning. The Planning Directorate is responsible for planning policy and the publication of Planning Policy Guidance notes.

Government offices for the regions

The ODPM is also responsible for the Government Offices for the Regions. These Regional Offices have a responsibility for developing regional planning frameworks, transport strategies, waste strategies, etc.

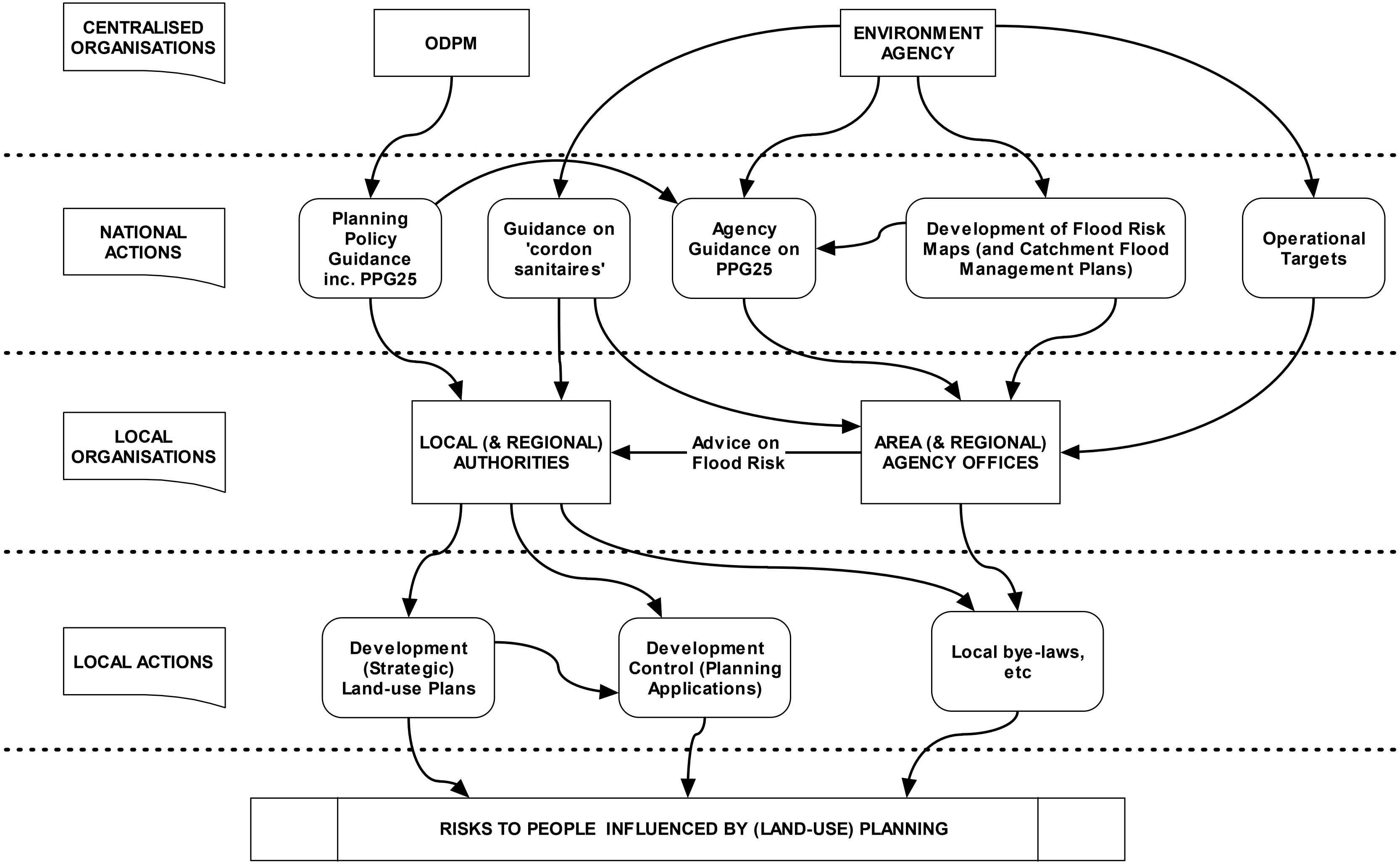

Figure 8.1 Schematic indicating how planning controls may influence risks to people

Local planning authorities

Local planning authorities have responsibilities for both development plans and development control (processing planning applications). However, the planning system will be undergoing major revisions (including the abandonment of county structure plans) with the introduction of the *Planning and Compulsory Purchase Act* in the next few months.

Planning in Wales

In Wales, planning is overseen by the National Assembly for Wales. The Planning Division comes under the Minister for Environment, Planning and Countryside. As for England, there are development plans that set the framework against which planning applications are determined (although the current system is liable to change with the introduction of the *Planning and Compulsory Purchase Act)*.

Environment Agency

The Agency is responsible for identifying areas at risk of flooding and for providing appropriate advice to planning authorities. In addition, the Agency has powers to limit works in close proximity to main rivers and to tidal defences.

8.2.3 Key actions and guidance

Flood risk mapping

As a result of the major floods in 1998 and 2000, the Agency initiated a major flood risk mapping exercise in England and Wales. This has resulted in the provision (by the Agency) of on-line flood risk maps. In the coming years, it is intended that the Agency will produce Catchment Flood Management Plans (CFMPs).

ODPM Planning Policy Guidance Note 25 (PPG25): Development and Flood Risk

Following the flood events of 1998 and 2000, there was disquiet that some of the flooding involved houses recently built in the floodplain. As a consequence, PPG25 was issued (with a similar guidance document currently being prepared in Wales to replace the older TAN15) which requires flood risk to be considered for all planning applications in the indicative floodplain. In essence, if it appears that the risk of internal flooding of the proposed developments exceeds once per 100 years for fluvial flooding or once per 200 years for tidal (i.e. coastal) flooding, there will be a presumption against granting planning permission.

Advice on development in the floodplain (with particular reference to planning applications) is provided to local planning authorities by the Agency. To ensure a degree of consistency in advice (and to ensure that advice is provided within the planning application timescales), advice from the Agency has been codified into a set of guidance notes (as listed in Box 8.1). It should be noted that for many planning applications in the floodplain, a flood risk assessment (FRA) will need to be submitted by the applicant to demonstrate an acceptable level of flood risk.

Box 8.1 Agency's guidance related to development and flood risk (completed and draft)

- **Safe access and egress to and from development**
- **Coastal Floodplain, Estuaries and Sea Defences**
- **Fluvial Floodplains and Washlands**
- **Tree Planting in Flood Risk Areas**
- **Strategic flood risk assessment**
- **Flood Risk Assessments (FRA) Matrix**
- **FRA Check List**
- **Flood Risk Assessment for Major Installations in the Flood Plain**
- **Objecting to Planning Applications**
- **Maintaining Watercourse Classifications**
- **PPG 25 Frequently asked Questions and Answers (Q and A Bank)**
- **Agency Policy and Practice for the Protection of Floodplains**
- **National Standing Advice to Local Planning Authorities for Planning Applications: Development and Flood Risk User Guidance Note (plus matrices)**
- **Environment Agency Guidance Relating to Planning Policy Guidance Note 25: Development and Flood Risk Assessments**
- **Procedure: Implementation of PPG25 on Development and Flood Risk within the Agency - Pre application advice and consultations on planning applications**
- **Policy and Practice for the Protection of Floodplains**
- **Floodplain Compensation**
- **Preparation of Survey Data for FRAs**
- **Climate change**
- **Development behind defences**
- **Freeboard**
- **Developed area**
- **Assessment of risk to people**
- **Demountable and temporary defences**
- **Tidal encroachment policy**
- **Developer contributions**
- **Development live**
- **Function floodplain**
- **Brownfield development**
- **Secondary defences and compartmentalisation**
- **Set back from defences**
- **Essential infrastructure**
- **Management of rainfall runoff and SUDS**
- **Policy Regarding Culverting**
- **Sustainable Drainage Systems**
- **Control of Development in Flood Risk Areas**
- **Land Drainage Consents**
- **Responding to Flood Risk Enquiries**
- **Enforcement**
- **Input into Regional Planning Guidance**
- **Input into Development Plans**
- **Pre-application advice and consultations on planning applications**
- **Outfalls Info Sheets**

The operation of PPG 25 is currently subject to a major review as there have been various difficulties in its operation. Whether it has significantly reduced the increase of numbers of the people within the floodplain remains to be seen.

National Agency Policy (and Actions)

The Agency has two general policy documents: *Making It Happen - Corporate Strategy 2002-07*; and *Corporate Plan 2003-06*. Both of these include consideration of flood risk with further detail provided in the Agency's *Strategy for Flood Risk Management (2003/4 – 2007/8)*. The aims of the Flood Risk Strategy (through cooperation with Defra and the Welsh Assembly) include the following:

- reduce the risk of flooding to life, major infrastructure, environmental assets and 80,000 homes; and
- reduce the proportion of properties in 'high risk' floodplains[6].

These aims, in turn, have led to priorities for change including:

- *Adoption of a Strategic Approach to Flood Risk Management*: The Agency envisages the adoption of a strategic approach involving a move away from flood 'defence' to flood 'risk reduction'. The focus will be on flood risk on a larger scale, and examination of pressures from climate change and development as precursors to flooding events. Such an approach will entail the development of relevant management plans, particularly Catchment Flood Management Plans (CFMPs), and the cooperation of stakeholder groups; and
- *Prevention of Inappropriate Development*: The Agency aims to prevent flooding due to development in 'high risk' flooding areas, through influencing planning policy and decision making. However to achieve this, Agency regulatory powers will require strengthening. Currently the Agency regulatory powers are limited to providing information and advice to planning authorities. The Agency aims to become a statutory consultee on flood risk by 2005, increasing their capacity to advise and inform local planning authorities (LPAs), and communicate with landowners and developers.

Local bye-laws

Under regional bye-laws (established under Land Drainage Acts), certain activities within 9m of main rivers (and associated river control works including defences) and within 10m of coastal defences (and associated facilities) require the consent of the Agency[7]. Such bye-laws are primarily intended to ensure that the Agency has access to river banks and coastal defences at all times. As such, it is unlikely that housing (and other) developments would be permitted very close (i.e. within a few metres) of flood defences.

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6 This is a re-statement of a long standing Government policy as, for example, stated in Defra's 1993 document: **Strategy for Flood and Coastal Defence in England and Wales**, London, MAFF

7 The distances quoted are based on the bye-laws for the Anglian Region. It is possible that the exact distances may vary by region - but this needs to be confirmed with the Agency.

8.2.4 Risks to people and planning

As noted previously (Section 8.1), the effective use of planning controls will limit the number of people at risk within the floodplain. At this stage, the methodology being developed is intended to estimate the current level of risk. As such, it is unlikely that planning issues can be factored into the methodology. Rather, the role of planning to limit future risks should be emphasised in areas where a high level of current risk has been identified.

8.3 Flood defence

8.3.1 Overview

As indicated above, the construction and maintenance of flood defences can limit the likelihood of flooding. Defra has responsibility in England for policy in respect of flood defence and coastal protection. In Wales, the responsibility for flood policy lies with the Secretary of State for Wales. However, jointly they administer the Coast Protection Act 1949, the Land Drainage Act 1991 and the flood defence provisions of the Water Resources Act 1991. These Acts empower the relevant operating authorities to undertake flood defence and coast protection measures, and enable Defra to significantly contribute to the funding of flood defence measures.

A schematic overview is presented in Figure 8.2 (overleaf) with further detail provided in the text below.

8.3.2 Key players

Defra

Although Defra has overall policy responsibility for flood and coastal erosion risk in England, it is not involved in the construction of flood defence structures nor advising authorities on which projects or maintenance to undertake. It is the operating authorities (the Agency, local authorities and internal drainage boards[8]) which assume responsibility for these work programmes.

ODPM

Whilst Defra (currently) provides the funding for capital works, the Office of the Deputy Prime Minister provides the funding for maintenance programmes (as well as funding for local authorities).

Environment Agency

The Agency supervises all matters relating to flood defence in England and Wales, including the design, construction and maintenance of flood and coastal defence works.

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8 However, this is due to change with the Environment Agency assuming responsibility for works programmes.

Flood Management Stakeholder Forum

In order to inform policy development, Defra established a Flood Management Stakeholder Forum (covering range of non-governmental stakeholder groups) in 2003. To date, the Forum has considered two key issues:

- implementation of the Funding Review (completed - see Section 8.3.3)
- the development of a new Flood Management and Coastal Protection Strategy (in progress).

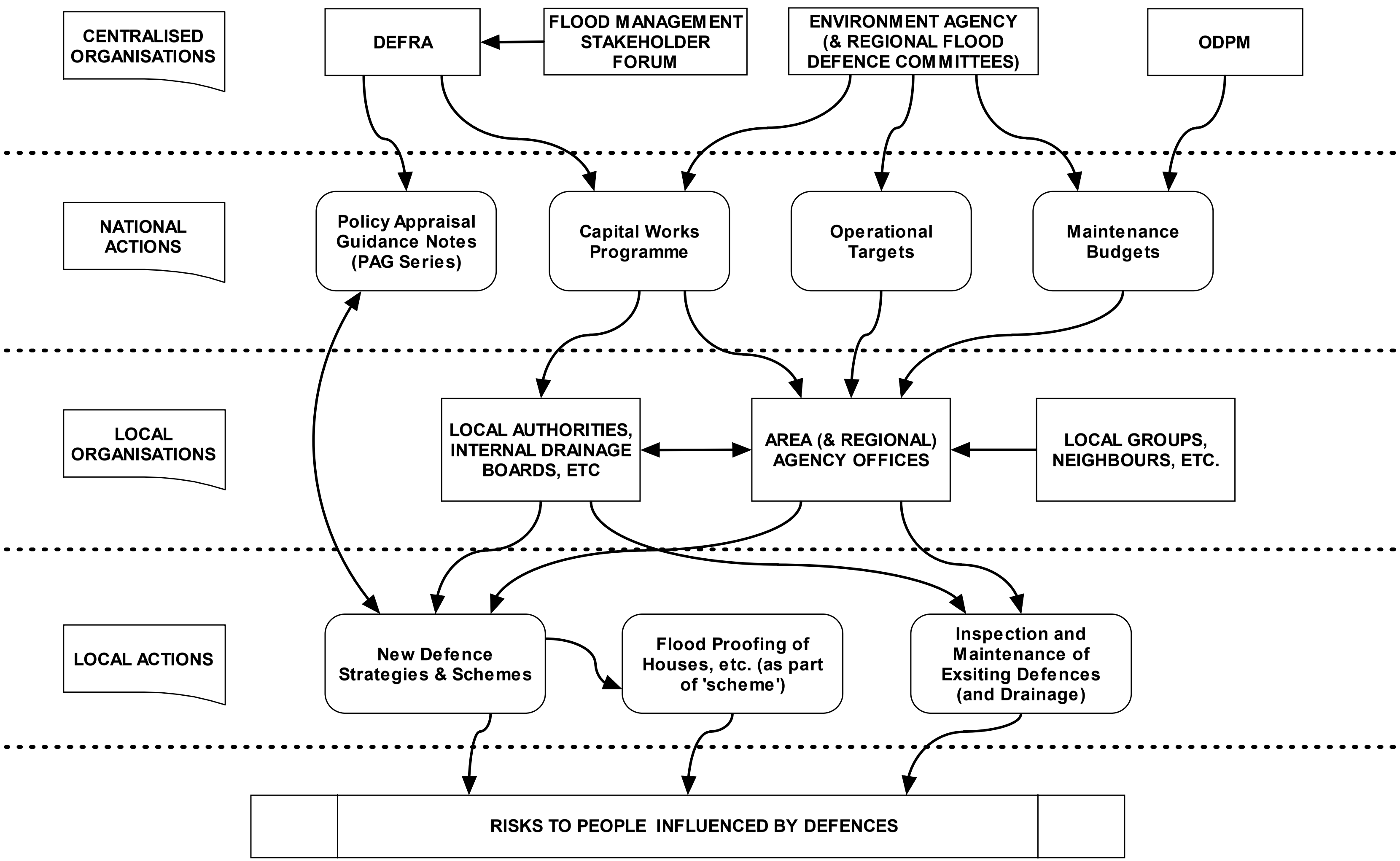

Figure 8.2 Schematic indicating how flood defences may influence risks to people

Regional Flood Defence Committees

The Regional Flood Defence Committees (RFDCs) are the administrative bodies through which the Agency exercises its flood defence functions and Box 8.2 provides some of the statutory powers of the RFDCs.

Box 8.2 Statutory powers of Regional Flood Defence Committees

RDFCs have the powers:

- to maintain or improve any watercourses that are designated as main rivers
- to maintain or improve any sea or tidal defences
- to install and operate flood warning equipment
- to control actions by riparian owners and occupiers which may interfere with the free-flow of water courses
- to supervise internal drainage boards.

The RFDCs are funded through the financial support the Agency receives from the government for revenue and running costs. There are nine committees in England and one in Wales. Local Flood Defence Committees (LFDCs) are also in place and their decisions are finalised and endorsed by the RFDCs. However, due to the recent Funding Review, the structure of FDCs will soon change (see Section 8.3.3).

Local authorities, internal drainage boards, etc.

Individual work schemes (both capital and maintenance) are undertaken by the operating authority - which is usually the Agency. However, Internal Drainage Boards, Local Authorities and Maritime Local Authorities also operate independently of the Agency, undertaking flood and coastal defence works that are not the responsibility of the Agency. However, overall responsibility falls to the Agency.

8.3.3 Key actions and guidance

Defra strategy

The *Strategy for Flood and Coastal Defence in England and Wale*s produced in 1993[9] details Defra's aims and objectives of reducing the risks to people and the developed and natural environment from flooding and erosion. The 1993 Strategy identified five main priorities which emphasised protection of life (the revised Strategy will expand upon this list to include priorities which deal with environmental issues). These are (in descending order):

1. flood warning systems
2. urban coastal defences
3. urban flood defences
4. rural coastal defences and existing rural flood defence drainage schemes
5. new rural flood defence and drainage schemes.

9 A new strategy is currently being developed with input from the National Flood Management Stakeholder Forum.

In relation to flood defence works, the following issues were identified as being integral to the strategic approach:

- *maintenance and management plans*: to ensure the protection of life, structure maintenance operations should be undertaken, however these should be sensitive towards environmental concerns. Additionally, water level management plans should take into account operational and environmental requirements (particularly in SSSIs)
- *appraisal procedures*: all schemes[10] should be deemed acceptable based on their technical soundness, environmental acceptability and economic viability
- *monitoring*: checks should be undertaken before, during and after the development of any scheme of works, warning system or construction of defence.

Flood and Coastal Defence Project Appraisal Guidance (FCDPAG Series)

In England and Wales, the development of strategies and schemes is governed by the FCDPAG series (often referred to as PAG3, PAG4, etc.) published by Defra (MAFF as was). In essence, for a project to gain funding from Defra, the proponent must demonstrate compliance with the guidance - with particular reference to its economic justification.

The FCDPAG series comprises six volumes:

- FCDPAG1 Overview
- FCDPAG2 Strategic planning and appraisal
- FCDPAG3 Economic appraisal
- FCDPAG4 Approaches to risk
- FCDPAG5 Environmental appraisal
- FCDPAG6 Post project evaluation.

Flood and coastal defence funding review

A review of flood and coastal defence funding was initiated in 2001 following the Government's Spending Review 2000. A consultation exercise was held in early 2002 which produced nearly 300 responses and in October 2002, Defra published its response to this consultation exercise. Planned changes to the funding arrangements were announced by the Minister in March 2003 with Defra producing a delivery plan in June 2003[11]. The most significant changes introduced by the funding review are outlined below.

Until 31 March 2004, Defra funded the Agency on a scheme by scheme basis for capital projects. However, as of 1 April 2004, Defra will no longer fund individual Agency schemes (except those above £5m with discretionary 'call-in' powers for schemes in the range £2-5m) but rather provides the Agency with a 'block' grant.

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10 'Schemes' is a broad term encompassing 'hard' defences (engineered structures), 'soft' defences (such as beach nourishment), creation of flood storage reservoirs (perhaps as 'natural' wetlands), demountable defences, flood-proofing of properties, improved water level management though the use of control structures, a comprehensive flood warning system, etc.

11 Defra (2003): **Delivery Plan for Implementing the Conclusions of the Flood and Coastal Defence Funding Review**, available on Defra's website.

The second major change resulting from the funding review, and using new powers in the Water Act 2003 (when enacted), is that Local FDCs are due to be abolished. They will be replaced by a single tier of FDCs, through the establishment of additional Regional FDCs. The aim of the restructuring is to reduce costs, and provide clearer and more efficient decision-making processes and programme management.

The third major change is that ordinary watercourses (i.e. not ‘main rivers’) currently the responsibility of local authorities (LAs) and/or internal drainage boards (IDBs) which present a significant flood risk (so-called critical ordinary watercourses) will become the responsibility of the Agency.

8.3.4 Risks to people and flood defence

As noted previously (Section 8.1), the provision of flood defences will limit the likelihood of flooding. Clearly, where flood defences are provided, the associated level of protection will be accounted for in the numerical determination of risks to those in the floodplain.

As for planning issues, where a high level of current risk has been identified, consideration should be given to the potential for risk reduction associated with the provision of new or improved flood defences.

8.4 Responses to flooding

8.4.1 Overview

As indicated above, responses to potential flood events can reduce the consequences of flooding. In particular, the operation of the Agency’s National Flood Warning Service is intended to provide a timely warning to those at risk of flooding. In addition, being prepared for a flood event can limit the associated consequences.

A schematic overview is presented in Figure 8.3 (overleaf) with further detail provided in the text below.

8.4.2 Key players

Meteorological Office

The Met Office is the national body responsible for providing weather forecasting information. This information includes forecasting those events which may lead to flooding from information gathered from satellites, water level/flow gauges, etc. and associated flood forecasting models.

Environment Agency

The Agency has an overall responsibility for the provision of flood warnings. The Agency is also active in promoting flood risk awareness and of working with local authorities and groups to improve flood response plans. The Agency have a new role in relation to the preparation of flood plans and emergency powers to reduce the risk of an escape of water from a large reservoir or artificially created lake.

Local authorities and emergency services

Local authorities have a general responsibility for the preparation of plans to respond to a wide range of potential disasters (train crashes, terrorist attacks, nuclear accidents, etc.) which may include flooding (depending on their location). Ideally, flood response plans will be based on inputs from local authorities, emergency services, area offices of the Agency and those at risk of flooding.

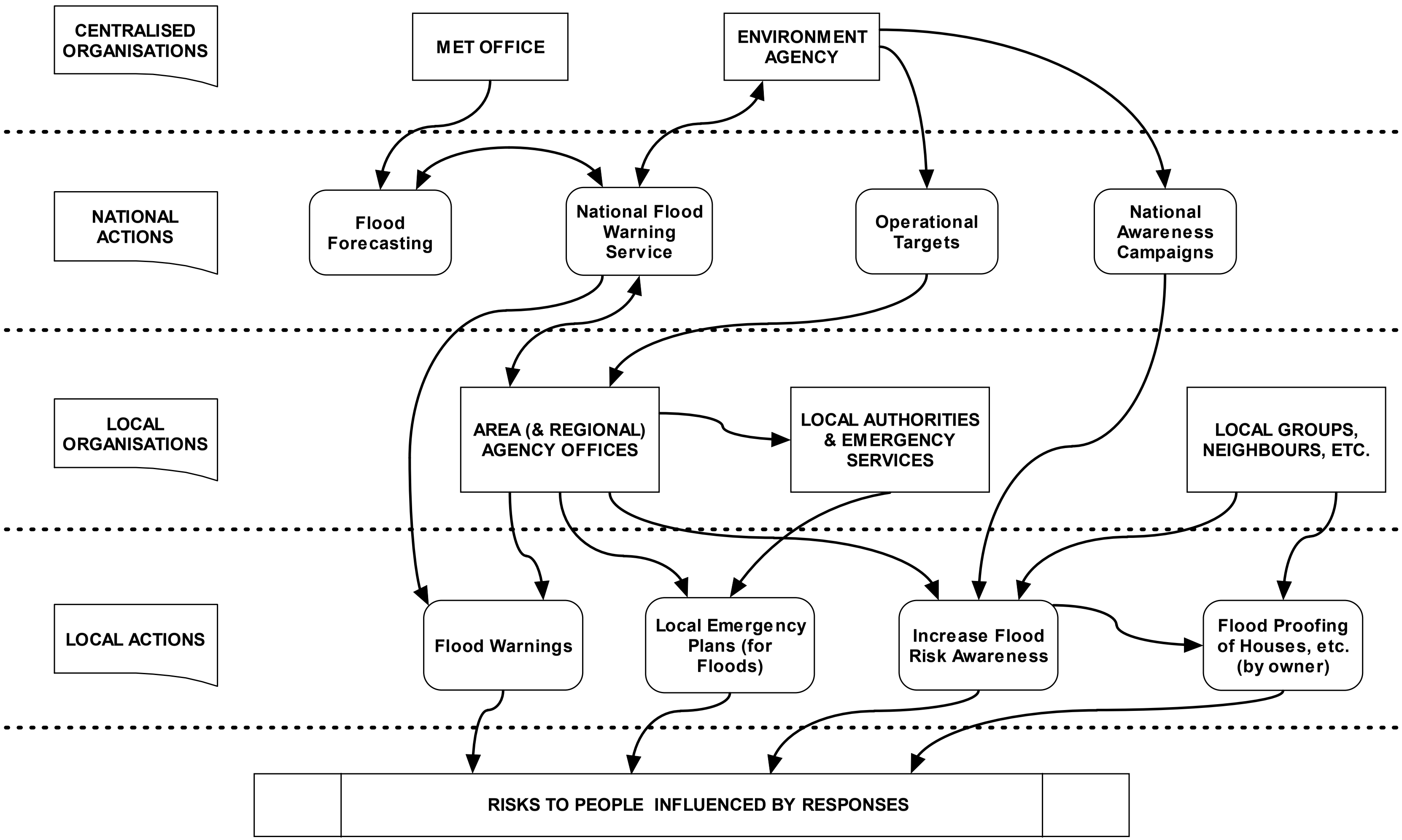

Figure 8.3 Schematic indicating how responses to flooding may influence risks to people

Local residents

At a local level, occupiers of property at risk of flooding (both domestic and non-domestic) may take actions to increase flood preparedness from simple steps (such as phoning *Floodline*) to investing in flood prevention/mitigation measures in the property.

8.4.3 Flood warnings - The Agency strategy

Agency Strategy Documents

The Agency has three key broad-ranging strategy documents (mentioned earlier) with a fourth focused on flood warning:

- *Making It Happen - Corporate Strategy 2002-07*
- *Corporate Plan 2003-06*
- *Strategy for Flood Risk Management (2003/4 - 2007/8)*
- *Flood Warning Investment Strategy (2003-2013).*

The key points (in relation to flood warning) from each are summarised below.

Making It Happen - Corporate Strategy 2002-07

The Agency has two key targets (to be met by 2007) in the Corporate Strategy:

- ensure that 75% of residents in flood risk areas will take effective action
- improve the coverage of flood warning services to 77% of properties in flood risk areas.

This will be achieved by providing information on flood risk to the public, stakeholders and developers, and pressing for policies on flood risk to be written into statutory plans. In addition, improved flood forecasting and flood warning services, encouraging community self-help groups, introducing multi-media dissemination of flood warnings and continuing the Agency's 10-year public awareness campaign will assist in meeting these targets. The long term vision of the Agency is thus:

> *"flood warnings will be given in good time, acted upon and damage minimised, and people will accept the need to avoid flood risks, take warnings seriously and act accordingly"*.

Corporate Plan 2003-06

The Corporate Plan plans the progress for delivering the targets set out in the Corporate Strategy. It is noted that around 1.2 million of the total 1.8 million (66%) of properties at risk in England and Wales are now covered by the flood warning system (although only 50% of these have 'registered' to receive flood warnings directly). In addition, the Plan states a longer term target than that given in the Corporate Strategy: *to increase the coverage of flood warning services to 80% of properties in flood risk areas by 2010.*

It is noted that the 80% target is close to the limit of what is possible, due to flash flooding. The Agency states that research shows that while 95% of people at risk agree that flooding is a serious issue, less than half (45%) accept that it relates to them. Furthermore, less than one in six takes any advance action to prepare for floods.

Strategy for Flood Risk Management (2003/4 – 2007/8)

This document sets out what the Agency and Flood Defence Committees will do to deliver the Government's overall policy aim of reducing flood risk over the next five years in more detail. In addition to those targets from the Corporate Strategy, the following target is also stated: to *have no loss of life through flooding (within the first three years of the Strategy)*.

Six key priorities for change are identified, which include reducing the impact of floods. This will be achieved through closer integration and streamlining of activities in **managing floods**, including flood planning, flood forecasting and warning, event management, response, flood event recording and reporting, after-care and recovery. Targets to increase the coverage, accuracy and reliability of flood warnings will deliver an extended and improved service to those at risk.

The Strategy suggests that the importance of flood warning and response is increasing with the added threat from extreme events resulting from climate change, and from the greater application of temporary/demountable defences and local flood protection products. Therefore, more investment in technology is needed to support flood forecasting, warning and response, as well as recording and reporting on flooding to measure the effectiveness of warnings and defences. With this in mind, the key milestones are identified as follows:

- by 2005, a nationally consistent approach to flood warning dissemination and information systems will be in operation. Flood warning codes will be applied to consistently identified flood warning areas, based on risk. A new multi-media warning dissemination system will be launched in September 2004
- by 2006, the Agency will have a nationally consistent approach to flood forecasting to improve forecast quality and allow extension of the service to meet the coverage target
- by 2006, the Agency will have a nationally consistent approach to flood warning decision-making with systems in place to ensure that relevant information can be assimilated effectively and used to support clear, accountable warning decisions
- by 2007, the Agency will have completed their planned programme of improvements to flood forecasting and flood warning service to provide a more effective warning service to at least 77% of properties in flood risk areas, and enable 75% of residents in flood risk areas to take effective action (i.e. as stated in the Corporate Strategy document).

Flood Warning Investment Strategy (2003-2013)

This document repeats the targets from the Corporate Strategy and focuses on work to improve coverage of flood warning services and influencing those at risk to take effective action.

8.4.4 Progress towards meeting flood warning targets

The Agency's *Annual Report 2002/03* restates the aim to provide 80% of those at risk of flooding with a two-hour warning by 2010. However, the Annual Report also records that the target to improve the coverage of flood warning services to high and medium flood risk areas to 70% by April 2003 was not met, with only 61% coverage[12]. It is reported that the definition and measurement for 'coverage' has been reviewed for the Agency's Flood Warning Investment Strategy, which is now defined as:

> "*the proportion of properties (homes and businesses) within the indicative floodplain that have been offered an appropriate flood warning service*".

In relation to the above objectives and targets, it is interesting to consider the floods in January 2003 (prior to issue of the *Flood Risk Management Strategy*), and the subsequent review of action undertaken by the Agency[13]. Over the Christmas and New Year period of 2002/2003, an extensive area of the country was affected by flooding. Over 800 properties were flooded from rivers where the Agency has flood defence powers. An additional 400 properties were flooded from other sources including groundwater, sewers, highway drains and from surface water.

Overall, it is reported that the delivery of warnings appears to have been successful with only minor revisions required. It is also reported that there was positive feedback from local stakeholders about the delivery of flood warnings. However, there is an issue relating to regional variations in the relationship between the number of flood warnings issued and the number of properties that flooded. For example, and as an extreme, in the Midlands, 118 flood warnings were issued and only five properties are reported to have flooded.

The Agency's Review identified that regions are making proper use of the Agency's Policy and Procedural Guidance for the creation and operation of its flood warnings. However, it is suggested that the Agency's Guidance needs some revisions. For example, flood warnings ("act now" code) are now perceived to warn of flooding to property. In fact, the Agency Guidance also allows them to be issued for significant flooding of land and this was the primary reason in the Midlands Region. These revisions had already been planned, and are indicated as such in the Agency's *Strategy for Flood Risk Management (2003/4 – 2007/8)*.

8.4.5 Flood warning in practice

Data on flood warnings

As part of a major Defra/Agency R&D project[14], nearly 1,000 people who had been flooded between 1998 and 2002 were interviewed in 30 locations across England and Wales. Most of the respondents were flooded during the major floods of Easter 1998 and October/November 2000. One of the key findings of the study was that only 299

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12 This conflicts with the 66% coverage reported in the Corporate Plan, which also relates to 2003.

13 Environment Agency (2003): **Review of New Year Floods 2003**, Open Board Paper, Item No. 7, Paper No. Ea (03) 11, Meeting Date: 19 March 2003.

14 RPA *et al* (2003): **The Appraisal of Human-Related Intangible Impacts of Flooding**, Final Report for R&D Project FD2005, dated November 2003.

(23%) of the 983 flooded respondents received a flood warning. The mean warning time (for those 204 respondents that did receive a warning and were able to provide an estimate of the warning time) was 16 hours. The Environment Agency is a major source of flood warnings, accounting for about 40% of the flood warnings received by the respondents.

Comparing Results from 1998 and 2000

To some extent, these statistics present a 'worst' case since, in some areas, flooding was due to drainage problems (as opposed to river flooding) for which the Environment Agency would not provide a flood warning in any event. The data have been revisited for those areas affected by river flooding during the major events of 1998 and 2000. The results are summarised in Tables 8.1 and 8.2 respectively.

Table 8.1 Flood warnings received for river flooding during Easter 1998 floods

Location	Nprop	Nresp	%FW	%FWs ≥2hrs	%FWs via EA
Alconbury, Cambs	90	28	25%	100%	71%
Banbury, Oxon	130	27	0%	n/a	n/a
Evesham, Worcs	75	21	33%	86%	43%
Hemingford, Cambs	40	10	70%	86%	0%
Leamington Spa, Warwickshire	400	101	5%	50%	0%
Melton Mowbray, Leics	100	18	0%	n/a	n/a
Newport Pagnell, Bucks	75	19	0%	n/a	n/a
Mean of above (by area)			19%	80%	29%

Notes:
Nprop = estimate of number of residential properties flooded in each location.
Nresp = number of 'flooded' respondents from each location.
%FW = percentage of respondents who received a flood warning (from any source).
%FWs ≥2hrs = the percentage of respondents (who indicated the flood warning time) who received a flood warning time of two or more hours.
%FWs via EA = the percentage of respondents (who specified the flood warning source) who specified the Environment Agency as the flood warning source (via EA automatic telephone system, EA Floodline or EA personnel).

Table 8.2 Flood warnings received for river flooding during Oct/Nov 2000 floods

Location	Nprop	Nresp	%FW	%FWs ≥2hrs	%FWs via EA
Newport, Gwent	130	52	12%	67%	0%
Ryde, Isle of Wight	75	17	53%	44%	89%
Barlby/Selby, N Yorks	150	48	48%	30%	13%
Gowdall, E Yorks	105	36	89%	100%	91%
Hatton, Derbys	140	39	18%	100%	14%
Lewes, E Sussex	550	159	36%	81%	52%
London Colney, Herts	40	10	0%	n/a	n/a
Ponteland, Northumberland	30	9	44%	100%	75%
Rhydymwyn, Wales	70	29	7%	0%	0%
Ruthin, Wales	180	62	10%	60%	17%
Waltham Abbey, Essex	120	30	0%	n/a	n/a
Weybridge, Surrey	55	6	83%	100%	100%
Woking, Surrey	30	10	60%	100%	50%
Worcester, Worcs	50	15	67%	100%	70%
York (Rawcliffe), N Yorks	85	29	0%	n/a	n/a
Mean (by area)			35%	74%	48%

Notes:
Parameters as in Table 8.1

By reviewing the data presented in Tables 8.1 and 8.2, a number of general observations can be made:

- as a consequence of the Easter 1998 floods, there is little doubt that the ability of the Agency to deliver flood warnings has improved significantly in recent years
- overall, the average percentage of respondents receiving a flood warning increased from 19% to 35% from Easter 1998 to October/November 2000 - but the percentages still fall a long way short of the Agency's long-term target of 80%
- where flood warnings were received, they tend to be of two or more hours (80% in 1998 and 74% in 2000)
- where flood warnings were received, the Environment Agency is a significant source accounting for 29% in 1998 and 48% in 2000.

However, the ability to deliver flood warnings is dependent on the nature of the catchment. As might be expected, those large catchments with a long (and predictable) lead time to flooding correspond to those areas with the highest percentage figures. For example, in 2000, both Gowdall and Worcester had several days lead time to flooding which facilitated the provision of long warning times by the Environment Agency. In other areas (notably in Surrey), the Agency was well prepared, enabling flood warnings to be delivered in a timely fashion.

8.4.6 Risks to people and flood warning

For flood warnings to be effective, there are three steps:

1. the correct prediction of a flood event in order to issue a flood warning
2. the dissemination of the flood warning to those at risk of flooding
3. for those receiving a flood warning to take appropriate action.

If the probabilities of these three steps are P1, P2 and P3 respectively, then the probability of someone taking the appropriate action is simply equal to P1 x P2 x P3.

If it is assumed (optimistically) that the probability of correct forecasting is 1.0 (100%), the probability of dissemination is taken as 0.8 (80% to be equivalent to the Agency's target of 80% 'coverage' by 2010) and the probability of correct action is 0.94 (94%), then the probability of correct action being taken is 1.0 x 0.8 x 0.94 = 0.75 (75%) which is equivalent to the Agency's target that 75% of residents in flood risk areas will take effective action.

Currently, more realistic values for P1, P2 and P3 might be 0.9, 0.7 and 0.6 respectively giving a combined probability of only 0.38 (38%) - and such views were advanced in earlier work for the Agency[15]. Of course, as indicated in the previous sub-section, particular values will vary from location to location depending on the nature of the catchment.

At one extreme, the probabilities for catchments with a slow response time, a history of flooding and very predictable flooding would be expected to approach unity for both forecasting and dissemination - although the probability of taking appropriate action might be somewhat lower.

At the other extreme, for rapid unpredictable events for which there is no (or little) previous experience, the probabilities would be very low. By way of example, in Rhydymwyn (2000 floods) where few received a warning, a seasonal river overflowed once a trash screen became blocked during heavy rainfall causing extensive flooding. Clearly, the provision of flood warnings by the Agency in this type of situation would be very difficult. Similar arguments would apply to the sudden failures of coastal defences or dams.

For other situations, it would be expected that flooding events would lead to improvements. By way of example, flooding in Leicestershire and Warwickshire during the Easter 1998 floods was unexpected (and hence no warnings were issued by the Agency) and action has now been taken to ensure that such events are less likely to occur in the future. Nevertheless, the average percentage (across 15 locations) of those that were flooded in 2000 receiving a flood warning was only 35% - suggesting that, in most areas, there is considerable room for improvement.

In relation to the methodology for estimating risks to people presented in the Phase 1 Report[16], the 'area vulnerability' score was based on three factors scored on a simple three point scale. These included 'flood warning' (essentially scored 'good', 'limited' or 'non-existent') and 'speed of onset' (essentially scored 'very gradual', 'gradual' or 'rapid' which is clearly related to the nature of the flood event and the catchment).

At this stage, it is considered that refinement of these factors based on a more detailed investigation of the effectiveness of flood warning is unlikely to significantly improve the performance of the methodology developed during Phase 1. However, it may well be possible to link the scoring system used for flood warning in the methodology to the

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15 Entec/RPA (1997): **Economic Benefits of Flood Warning and Forecasting: Phase 1**, Agency R&D Technical Report W53.

16 Ramsbottom D *et al* (2003): **Flood Risks to People Phase 1**, Defra/Agency R&D Technical Report FD2317 dated July 2003.

some of the performance indicators being used by the Agency (for example, Measure 218B[17] is the percentage of properties (homes and businesses) within the indicative floodplain that have been offered an appropriate flood warning service). This aspect will be considered further in the next stage of the work and the flood warning component of the area vulnerability will be linked to the Key Performance Indicators (KPIs).

8.5 Flood warnings and risk to life - insight from the research literature

Introduction

Timely flood warnings are increasingly being considered a key element in aiding disaster preparedness and thus greatly reducing human suffering (Aziz *et al*. 2002). The situation in the last three decades across Europe is shown in Figure 8.4, and it appears that the increase in the coverage and effectiveness of warning systems is the main cause of the negative correlation between flood incidence and loss of life (Penning-Rowsell et al. 2004).

Indeed it is apparent now that the main goals of flood warnings are to reduce loss of life from floods, as well as reduce property damage and general disruption to everyday life (IFLOWS, undated). Moreover it would also appear that non-structural methods of flood mitigation such as warnings are cost-effective compared to structural ones (e.g. dams and levees) and are increasingly finding favour in flood prone countries (Aziz *et al.*, 2002). Also, non-structural methods have been used in places where no satisfactory structural solution could be used (US Geological Survey, 1998).

The factors influencing the effectiveness of flood warnings in reducing loss of life and serious injury

The results and effects of warnings are strongly dependent on the lead time. The lead time is the main difference between slow-rising riverine floods and flash floods (Rosenthal and Bezuyen, 2000). Flash floods occur within several seconds to several hours, often with little or no warning (Perry, 2000).

Flood warning and warning time have been used to model the number of fatalities that may be caused by a flood. Jonkman *et al*. (2002) reviewed a series of methods available in literature to estimate the loss of life caused by floods. Brown and Graham (1988) propose loss of life as a function of the population and the time available for evacuation (i.e. warning). The procedure is derived from the analysis of 24 major dam failures and the consequential flash floods.

For DeKay and McClelland (1993) loss of life is also a function of population and evacuation time, but they distinguish between 'high lethality' floods, for example in a canyon and 'low lethality' floods, for example on a floodplain. In both functions, loss of life decreases very quickly when warning time is increased. Graham (1999) presented a

[17] Measure 218B relates to England and Measure 218A relates to Wales. Although the unit of measurement is the same, the targets are different (77% by 2006/07 for England and, as yet, unspecified for Wales).

framework for estimating loss of life due to dam failures based on the flood severity, the amount of warning and the understanding of the population of the flood severity (see table 8.3, from Jonkman et al 2002). Three categories of warnings are given: no warning, some warning (15-60 minutes) and adequate warning (> 60 minutes). According to this model, adequate warning greatly reduces the fatality rate in flood events.

The literature also shows several real life examples that illustrate the effectiveness of flood warnings in reducing risk to life and serious injury from both slow rising and flash floods. For instance, in the summer of 1997 extremely heavy rainfall in large areas of Eastern Europe caused over 100 casualties and huge economic losses. A third of the territory of the Czech Republic was affected by floods and 60 people were killed. In Poland 54 people died. However, in Germany the flooding of the River Oder did not cause any loss of life. Admittedly, the area that was flooded in Germany was comparatively small and breaches in Polish dikes provided some relief (Koppe, 1999) but also the flood warning lead time was longer and in view of the absence of casualties it becomes apparent that this extra warning time was properly used (Rosenthal and Bezuyen, 2000).

In contrast, the 1993 Mississippi floods, which caused 50 deaths, highlighted several shortcomings and inaccuracies of flood forecasting systems in the United States. The 1993 floods were the worst recorded flood in the United States in terms of precipitation amounts, water levels, extent and duration of flooding, number of people displaced and damage to property and crops (Bruen, 1999).

Flash floods are relatively frequent events that sometimes, but not always, are accompanied by timely warnings (Gruntfest and Ripps, 2000). For example, Jamaica suffers frequent flash flooding, often with a very short lead time, associated with tropical cyclone situations. On average, there is at least one catastrophic flood every four years and since the year 1800, 54 major floods have occurred in the island causing 273 casualties. Since 1991, several flood warning systems have been implemented in Jamaica. The saving of lives is one of the successes recorded for the use of these flood warning systems (Douglas, 2003) but the cyclone events in summer 2004 show that residual loss of life can still be considerable.

Loss of life and the absence of warning occurred in the following flash flood examples. On 31 July 1976 a flash flood killed 139 people in the Big Thompson Canyon near Estes Park, Colorado. Most people did not receive official flood warning and official warnings were not issued until the flooding had occurred. On 14 June 1990 12.7 cm of rain fell during just over an hour at the headwaters of two creeks raising the water level as high as 9 m above their stream beds. The flood killed 24 people in Shadsyde, Ohio. Public awareness of the possibility of a flash flood of this magnitude was non-existent (Gruntfest and Ripps, 2000).

Failure of dams and levees can also create flash floods that are catastrophic to life due to the enormous energy of the released water. Warnings of the Teton Dam failure in Idaho in June 1976 reduced the loss of life to 11 people (Perry, 2000).

The situation in the UK

There is little research in the UK that directly addresses this question. The 1953 East Coast floods, in which over 300 people lost their lives (EAb), have been described as the 'worst national peacetime disaster' (EAa). The existence of proper flood warnings would have greatly reduced the number of victims by allowing enough time for evacuation (EAa). In the 1998 Easter Floods five people lost their lives. The majority of people affected by this flood did not receive a warning (Bye and Horner, 1998).

However, no loss of life directly attributable to flooding occurred during autumn 2000, when England suffered devastating river flooding. Flood warnings provided by the EA during the event were generally accurate and the event had such a long duration that the public was fully alerted to the threats that the flood imposed (Kelman, 2001).

The research literature: summary assessment

The literature shows that there is (negative) correlation between effective warnings (or lack of) and loss of life in a flood event. Although there are other issues regarding flood warnings such as people's responses to them, it seems clear that timely and effective flood warnings help to reduce risk to life and serious injury from flooding, although the research literature in the UK is relatively sparse as to detailed analyses.

Table 1 Fatality rates derived for dam breaks as a function of flood severity, amount of warning and understanding of the flood severity (Graham, 1999)

Flood Severity	Warning Time (minutes)	Flood Severity Understanding	Fatality Rate (Fraction of people at risk expected to die)	
			Suggested	Suggested Range
HIGH	no warning	not applicable	0.75	0.30 to 1.00
	15 to 60	vague	Use the values shown above and apply to the number of people who remain in the dam failure floodplain after warnings are issued. No guidance is provided on how many people will remain in the floodplain.	
		precise		
	more than 60	vague		
		precise		
MBDIUM	no warning	not applicable	0.15	0.03 to 0.35
	15 to 60	vague	0.04	0.01 to 0.08
		precise	0.02	0.005 to 0.04
	more than 60	vague	0.03	0.005 to 0.06
		precise	0.01	0.002 to 0.02
LOW	no warning	not applicable	0.01	0.0 to 0.02
	15 to 60	vague	0.007	0.0 to 0.015
		precise	0.002	0.0 to 0.004
	more than 60	vague	0.0003	0.0 to 0.0006
		precise	0.0002	0.0 to 0.0004

Table 8-3 Fatality rates from dambreaks

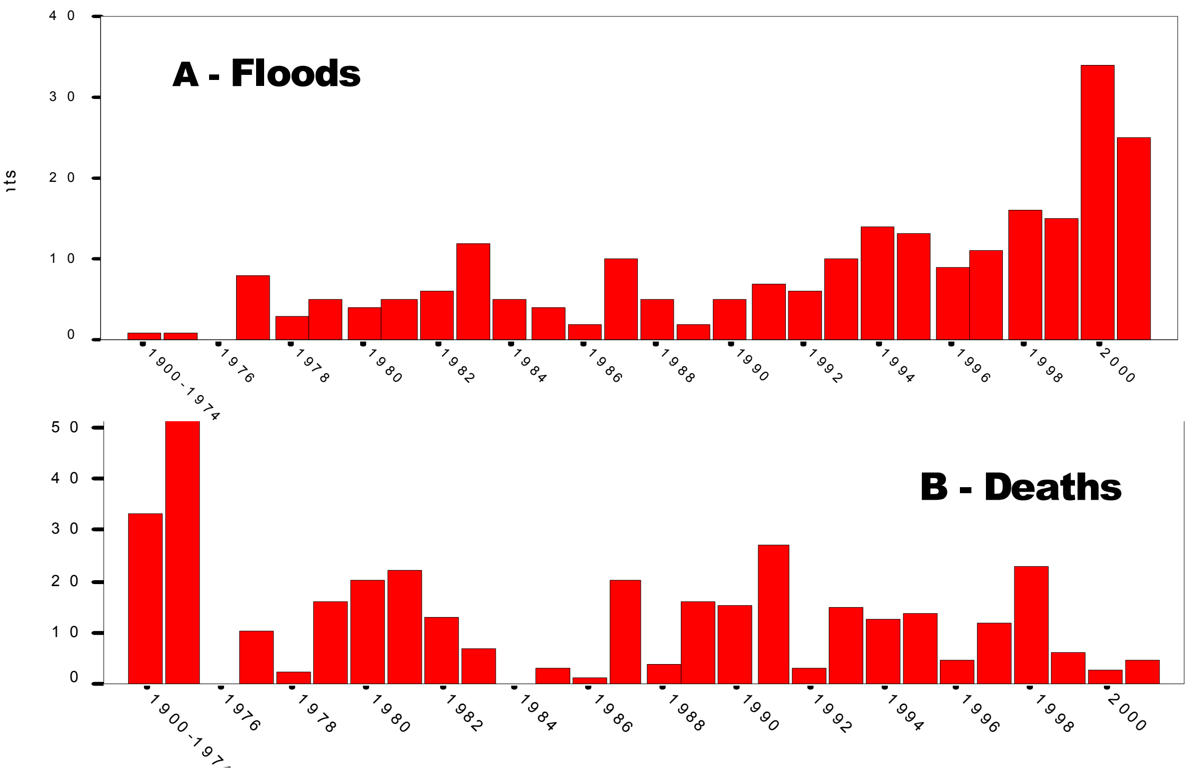

Figure 8.4: Floods and loss of life in Europe since the early 1970s (source: WHO)

8.6 Flood warnings and risk to life - insight from the "Roadtesting" project

In parallel with the Risk to Life project, the Flood Hazard Research Centre at Middlesex University has been undertaking a project for Defra to look at the damage reduction likely to occur as a result of flood warnings being issued to those in flood risk areas. This is part of a wider "Roadtesting" project, designed to test the FHRC Multi-coloured Manual for use within the flood and coastal defence community.

Methods and approaches

As part of the work on flood warnings and damage reduction, focus groups have been held to discuss a range of issues concerned with warnings and their effectiveness. This work has been dominated by a "bottom up" methodology, designed to elicit from the flood victims (i.e. those who have experienced flooding inside their properties) information about the way that flood warnings are received, the actions that follow from those warnings, and hence the damage reduction that can result.

In addition, however, some questions were asked the participants of these focus groups about public safety aspects of warnings. For example they were asked "what their priorities were upon receipt of a flood warning", and "what their priorities were when they first became aware of a flood threat". These questions were unprompted (methodologically important), within an exercise more concerned with flood damage reduction than public safety issues. As such they are valuable in assessing the public's perception of the safety aspects of warnings, and the way that information on safety aspects is transmitted to them.

Focus groups have been held in Worcester, Sunbury, Wraysbury, Halstead (Essex) and Woodford Green (Essex). These relate to the Severn, Thames and Essex river catchments. Not all the same focus groups were the same size, but the mean size was 6 participants, giving a total of approximately 30 participants in all. As such these focus groups are quite small, because they include only those who have been flood victims (although in one case one participant had not been flooded in their property, but only adjacent to their property).

As far as the full results are concerned, we are still awaiting full transcripts of the focus group discussions. Therefore these results here are prepared in summary form ahead of those details being available, but we feel this summary is representative of the views coming from the focus group participants.

The summary results

Safety aspects of flood warnings in terms of reducing risk of loss of life or reducing the risk of serious injury, were not a dominant theme amongst the focus group discussions. This was despite this area of discussion being prompted by the question posed above about priorities, and despite the fact that all participants had had flood waters in their properties. Indeed only a small minority (probably 10-15%) of the participants made unprompted comments upon safety aspects; this was clearly not their primary concern.

Where there was a mention of safety aspects, respondents made the following kinds of comments:

> *"Warnings are about making sure the family were safe"*
> *"We need to make sure that pets are safe"*
> *"We use the warnings to make sure our neighbours are safe"*
> *"Checking on neighbours"*
> *"Going to help neighbours"*

So what we see here is that those concerned with safety have the wellbeing of their family and neighbours at heart, but as indicated above this is not a primary concern and not a major priority upon receipt of flood warning. Indeed the primary priority was attempting to reduce damage, after focussing on confirmation of the message.

It would appear that the reason for the above situation is that the floods being discussed (and floods in general in the UK) are perceived as being shallow and slow moving, rather than deep and dangerous. When asked within the focus groups whether participants wanted more information about safety issues in the warnings they received, the general consensus was negative. What participants needed was confirmation of the threat, together with the timing, and depth of the likely flood water. The motivation is saving damage, and a critical factor is whether the water will enter their properties. They wanted much more detail in the warnings, in particularly about depth and velocities, and when the flood would peak. Indeed many of the respondents have been watching the flood waters rise and again the crucial variable required of them personally was the likelihood of their property being flooded above threshold level, and many participants were effectively 'calculating' of the likelihood of this happening after receipt of the warning and before the onset of flooding.

Personal risk was not central to their considerations; property, not loss of life was uppermost in their thoughts. To some extent this is contradicted by the fact that those experiencing flooding (particularly those experiencing the floodwater outside their properties) were surprised how fast flowing the waters were, surprised at the power of the flood, and the speed of onset. There was talk of "waves of water" coming up streets, "tidal waves", and "fast" moving waters posing somewhat of a threat. But these comments came from a minority of respondents.

We also questioned our participants as to whether warnings or false warnings had led to any danger in themselves as a result of actions taken threatening health of serious injury. The answer to this was negative and a parallel project on the "Intangible" effects of floods on health found that the degree of injury is small in many warning situations, contrary to some emphases in the research literature. One participant thought that false warnings were a "nuisance" but in general this line of enquiry was not fruitful.

The "Roadtesting" data: summary assessment

In summary, what we find is that those suffering flooding, and receiving flood warnings, do not see public safety issues as of significant importance: perhaps this is because public safety issues of flood warnings are 'taken as read', rather than them being unimportant in themselves. There was a recognition by those who had experienced flooding that velocity and speed of flood waters, combined with high flood depth, could be dangerous, but this was not the experience of most participants. Therefore any flood warning did not bring connotations of those flood characteristics to the fore, rather damage reduction and the avoidance of nuisance and inconvenience was dominant within the messages underlying flood warnings received by our focus group participants.

When we have more detailed information from the transcripts of the focus group discussions we may be able to add some depth to the above analysis and summary. However, despite considerable effort in this direction, we do not find a strong link between warnings and useful information on the potential for loss of life or serious injury. Maybe this should be the case, but empirically we have not found a strong connection between these phenomena.

8.7 Flood warnings and risk to life - insight from initial interviews with senior flood and coast defence 'actors'

One component of this research, as specified in the Terms of Reference, was a set of interviews with key players in the Environment Agency, Local Authority and Defra. The results were to be used in the overall refinement of the method.

The interviews

We have concentrated on interviewing senior staff who would have the clearest policy overview. The interviews have been informal, extending to perhaps 1.5 hours in duration each, focussing on a range of aspects related to flood warning and flood mapping. The reason for this focus is that the rationale for this survey would appear to be determining how to interface the mapping of flood risk with factors involving loss of life and serious injury, and the provision of warnings so that this risk can be reduced.

The results

Table 8.4 gives a summary of the results from these interviews. What this indicates is unanimous support that preventing loss of life and serious injury should be top priority aims for flood warning systems. There is agreement across Defra, Local Government and EA representatives on this matter. There is also agreement as to the real aims of flood forecasting and warning systems, in allowing responsible organisations to take preparatory actions, informing Local Authorities and the general public, and "to alert people at risk to save their lives and property". The reasons given for the high priority differ across the interviewees, but there is general agreement that flood policy (including flood mapping and flood warning) should focus on loss of life and serious injury as a major benefit of increased effectiveness and accuracy.

In many respects the 4th question topic area is the crux of this matter (Table 8.4). Here we asked "How should we incorporate the effects of warnings on reducing loss of life and serious injury into our floodplain mapping systems". This is a complex question, involving the integration of two sets of information, but this question goes to the heart of the Risk to Life project.

What we see are somewhat different emphases coming from the discussions and within the interviews. The Defra senior engineer could see how this matter could be done, to identify “hot spots” within floodplain maps, indicating areas where the risk of loss of life or serious injury was more significant than in other areas. The interviewee saw this as part of an evolution of floodplain mapping methods, which will include more information for the general public and responsible agencies in a process described as an evolution towards “zonal flood mapping”.

On the other hand the Local Government representative saw considerable problems, not least because floods occur outside indicative floodplains as currently mapped and there are serious risks here, not least in the urban areas. Also, and related to this point, is the suggestion that more comprehensive flood maps might give a false sense of security to those areas shown not to be in the indicative floodplain but which could flood. Death or serious injury outside the indicative floodplain resulting from flooding could result in a challenge to those agencies creating these maps, on the basis that the public might have been informed about risks but were not in those circumstance. This is a serious issue that the Risk to Life project needs to consider.

The senior Environment Agency representative saw the bringing together of floodplain maps and warnings of loss of life and serious injury as a difficult interface. There is a need to warn the public, and there is information the public needs to know. Warning maps are not currently made publicly available, and the indicative floodplain maps do no contain information on flood warnings and their effectiveness or even their presence and absence. Again, at the back of the interviewee’s mind is the question of challenge and of responsibility, and this is particularly problematic where floodplain maps showed defences which have a finite probability of failure. It is a difficult matter to decide whether this type of area should be shown as one where there is serious risk to life and serious injury. That there is such a risk is undeniable, but the probability element of that risk is very low and the public might be unduly concerned (for example if all the area protected by the Thames Barrier was shown to have a risk of loss of life and injury from potential flooding).

The Defra/EA/LGA interviews: summary assessment

What we get from these interviews, in summary, is an explicit recognition that loss of life and serious injury is a top policy priority. There is also a recognition that bringing together loss of life and serious injury information with floodplain maps is technically possible but brings policy and ethical dilemmas. The information could be misinterpreted, or the public could challenge an organisation providing such data if death or serious injury occurs outside the area shown to present such risks on the maps provided. Therefore any information on risk to life and serious injury must take on board this point, and show such risks as low, and show other areas as not without risk.

Table 8.4: Responses from interviews concerning the flood risk mapping and flood warning interface

Interviewee / Question topic area	Defra senior engineer	Local Government councillor/LGA18 representative	Senior Environment Agency representative
What are flood forecasting and warning systems really for?	"So that we can take preparatory actions".	"To better inform us in what we can do as a Local Authority, and to pass on to the public".	"To alert people at risk, to save their lives and property".
How do you rate preventing loss of life and serious injury as aims for flood warning systems?	"Warnings per se very high. Loss of life very/top priority".	"Top priority, all other things being equal".	"Top priority".
Why?	"In warnings, several aspects need to be balanced. Warnings are critical in allowing preventing water entering properties: Autumn 2000 showed the protection of several 100,000s properties in this way".	"As a politician, preventing loss of life and serious injury must be top priority".	"What is worse than losing a life. It could be you or yours".
How should we incorporate the effects of warnings on reducing loss of life and serious injury into our floodplain mapping systems?	"RASP type overlay incorporating depth and high velocity areas, to identify 'hot spots' where risk is especially high. Certainly worth thinking about, as we extend to zonal flood mapping".	"Laudable but …. providing it is clear and unambiguous and not subject to challenge, then we should try to do this. But we must not give a false sense of security (for the areas not identified as 'hot spots'). Flood risk can be outside the IFM and people can be killed there".	"That's a tricky one. They, the public at risk, need to know. There are warning systems in place, therefore coverage needs to be mapped and warning methods linked to that (sirens?). The maps are there to inform the general public, but where there are defences that might fail, this is a problem".

18 Local Government Association

8.8 Flooding, pollution and associated risks

8.8.1 Introduction

Floods can have indirect impacts on human health. Pollution caused by the flooding of installations that store or produce toxic chemicals can have potential effects on human health, although there is very little systematic research on this area. No demonstrable correlation between contamination by toxic chemicals and flooding has been found so far (WHO). However, since the 1998 Easter floods there has been a series of flooding incidents that have caused problems to a number of hazardous sites in the UK.

The paucity of research on the effects of pollution caused by flooding on human health should not lead us to be complacent. It is likely that floods will increase in frequency and intensity in the near future (Hajat *et al*, 2003). Increased population on floodplains, together with the growth of industrial activities in those areas have contributed to a number of human catastrophes. Although these accidents have been more acute in the developing world, certain parts of Europe (particularly in the south and east) are showing similar trends (Kirchsteiger, 1999).

8.8.2 Facilities of interest

Due to the absence of important flooding during the 1980s and early 1990s, flooding was not considered a major issue in this country and thus planning permission was granted by Local Authorities for developments in flood plains (Whitfield, 2002a).

Locations on floodplains offer a series of advantages such as level building grounds, good transport links, a supply of cooling water and easy discharge route for effluents (Whitfield, 2002a). As a consequence there are a number of industrial sites located in flood plains. These sites include:

- COMAH sites; and
- PPC sites.

The COMAH *(Control of Major Accident Hazard) Regulations 1999* implement *EC Directive 96/82/EC* (known as the *Seveso II Directive*). They cover sites in the UK that use or store dangerous substances such as oils, gases, chemicals or explosives. The Environment Agency together with the Health and Safety Executive (HSE) is the Competent Authority to implement these regulations for England and Wales. The aim of the COMAH regulations is to prevent major accidents occurring in these sites (Environment Agency). These regulations apply to over 1100 sites in England, Wales and Scotland. Approximately 750 are 'lower tier' sites and the remaining 350 with larger inventories of dangerous substances are classified as 'top tier' (HSE, 2003).

The PPC (*Pollution Prevention and Control*) regulations implement the EU *Integrated Pollution Prevention and Control* (IPPC) *Directive* in the UK. The aim of PPC is the regulation of certain industrial activities that generate emissions to air, water and other environmental effects. PPC is gradually replacing the IPC system that was established under the Environmental Protection Act 1990 to control pollution from industry.

Landfill sites are another type of installation that can be often found on floodplains. However there are no records of injuries or death to people due to pollution caused by flooding of a landfill. It is accepted that should floodwaters engulf a landfill (and, indeed, other waste collection/management facilities), there is a possibility that the floodwaters may become polluted. In relation to direct risks to people, it could be argued that such polluted water could lead to illnesses amongst people exposed to it. However, to date, no evidence has been found to support this assertion. On this basis, it is concluded that it is very unlikely that landfills present a significant 'risk to people'.

8.8.3 Numbers of facilities

A significant number of properties are located within the indicative floodplains[19] of England and Wales. It would be expected that there are significant numbers of facilities with the potential for harm also located within the indicative floodplain.

Data have been provided by the Environment Agency[20] which details:

- the numbers of landfills within both tidal and fluvial floodplains
- the numbers of sites (and authorisations) under the Integrated Pollution Control (IPC) Regulations (which are now being replaced by the Pollution Prevention and Control (PPC) Regulations) within the tidal and fluvial floodplains
- the numbers of sites listed under the Control of Major Accident Hazards (COMAH) Regulations (both top and lower tier sites) within both tidal and fluvial floodplains.

The results are summarised in Table 8.5 and the variation by region is illustrated in Figure 1 (Appendix D).

Table 8.5 Approximate numbers of facilities within the Indicative Floodplains (IFP) of England and Wales

Type of Facility	Number in IFP	%Tidal	Total (EandW)	% in IFP
Landfill	513	32%	1690	30%
IPC Site	281	64%	1320	21%
COMAH Site	172	74%	1100	16%

Sources: The national totals are (RPA) estimates based on data from the Agency website (landfills), Friends of the Earth (IPC sites for 1999/2000) and HSE website (COMAH).

8.8.4 An example of a pollution-related flooding incident

The flooding of a waste treatment and storage site (a designated COMAH site) run by Cleansing Service Group in Sandhurst (near Gloucester), following a fire brought into light the risks of flooding at major hazard sites (Whitfield, 2002; HSE, 2003).

The fire was caused by an explosion in a storage area for hazardous chemicals, on the 30th of October 2000. The cause of the explosion has not been determined

19 For fluvial flooding, the indicative floodplain extends to the 1 in 100 year contour and for tidal flooding, the indicative floodplain extends to the 1 in 200 year contour.

20 However, some parts of the data have been 'scrambled' and the Environment Agency has been asked to provide an unscrambled version. As such, the analysis presented here cannot be relied upon at present as some of the numbers are liable to change.

(Environment Agency, 2003). Approximately 180 tonnes of chemical wastes were consumed in the fire. Sixty people were evacuated from their houses and another 13 people were taken to hospital, although no one was admitted and no members of the public appear to have been injured (HSE/EA, 2001). The Environment Agency flood warnings indicated that the site, which is situated alongside the River Severn, would be flooded in the next few days. Action was taken to remove fire damaged and other materials out of the reach of the waters (Whitfield, 2002).

The most severe floods in the area since 1947 occurred during the following days causing local residents to be evacuated again (National Steering Committee, 2001). The site was flooded on the 3rd of November and could only be accessed by boat, which hindered the investigation and clean up (Whitfield, 2002b). A drum containing arsenic and selenium was found to have leaked and was showing sings of further reacting with water and causing gaseous emissions and there were seven 25 litre containers which were thought to contain BSE contaminated tissues present in the site (Environment Agency, 2001). Serious flooding continued for three weeks and the site was flooded again in December (Whitfield, 2002b). It is worth noting that, one year earlier, HSE had agreed to a request form the local council to investigate potential releases due to major flooding (HSE, 2001).

During the weeks following the incident a large number of residents reported illness (Whitfield, 2002b). On the days following the flooding there was a common complaint among the public of a strong sulphurous smell, which was attributed to the combustion (Environment Agency, 2001). Although the flooding hampered the clean-up operations and led, inevitably, to some pollution. The environmental tests carried out by the Environment Agency and the Tewkesbury Borough Council did not yield any significant levels of off-site contamination. The Gloucester Health Authority does not believe that there will be any long term health effects caused by the accident but monitoring the health of the local population is continuing (Whitfield, 2002b).

Overall, the incident was serious enough to be one of the four incidents at a COMAH facility during the year 2000/01 to be reported to the European Commission (HSE, 2003).

Following the CSG accident, the Environment Agency decided to review the risk posed by industrial sites that are subject to flooding (Environment Agency, 2001). The issue of how many COMAH sites are at risk of flooding was also raised by the CSG incident. Taking a long term view, the potential increase in flooding due to climate change and the increasing age of these sites and their equipment is a cause of concern for the Environment Agency. Much of the equipment used in the process industries was built in the 1960s (Whitfield, 2002b).

8.8.5 Examples of incidents elsewhere

Introduction

Concerns about flooding of chemical installations are not exclusive to the UK the Central Europe floods of August 2002 did not only left damaged chemical plants but also raised concerns among chemical companies about an increase in insurance and flood prevention costs due to floods being more likely (Milmo, 2002).

In the Czech Republic, the worst floods in 500 years put several chemical sites under water. Ninety percent of the Spolana site on the River Elbe was at one point covered in floodwater. The site leaked chlorine on three occasions and there were fears that large quantities of dioxins and mercury could be washed into the Elbe (Milmo, 2002). In November 2002 Greenpeace reported (Greenpeace, 2002) high levels of dioxins and polychlorbifenyls (PCBs) in soil and food samples taken in the vicinity of the Spolana site. Farm products in the area around the site were later declared inedible by health authorities due to excessive amounts of toxic substances. The definite cause of this contamination has not been established yet but the flooding of the site is one of the possible explanations (Tax, 2003).

Indirect effects

The Spolana incident is an example of direct impact of contaminated floodwaters, in which the water has the role of transporting the pollutants e.g. into a river or a populated area.

Water can also react with chemicals and produce gaseous emissions (Environment Agency, 2001) or even explosions. In 1982, during heavy rains, rainwater reacted with sulphur trioxide leaking from old storage drums causing several explosions at the Staveley Chemicals Limited site in Derbyshire, although no one was injured (HSE, 1982). Floodwaters reacting with phosphorous caused a blast in an ammunition dump in Loures, Portugal during a flood in 1967. Twelve people were injured and three thousand people were evacuated from the area after the blast (Lloyds Weekly Casualty Reports, 1967). More recently, flooding initiated an explosion in an oil refinery in Morocco that killed two people in 2002. Water caused leaks and the hot oil was brought into contact with the hot parts of the refinery, causing explosions and a fire (Quarterly Loss Report, 2002).

Floods may also damage other infrastructures such as rail tracks or pipelines thus leading to explosions, fires and toxic releases. On 20 and 21 October 1994, heavy rainfall caused the San Jacinto River near Houston (Texas) to overflow its banks washing away the soil supporting eight pipelines. The exposure combined with internal pressure caused four pipelines to break (Tucson Citizen, 2003). What was broken were a gasoline pipeline, a diesel fuel pipeline, a natural gas pipeline, and a light crude oil line. As the gasoline found ignition sources, fires and explosions quickly followed and houses, office buildings, boats, cars and barges were damaged or destroyed (ISPR, 1996). Following the incident, there were 1,851 injuries that required medical treatment (Office of Pipeline Safety, 1994) most of them minor burns or respiratory ailments (Tucson Citizen, 2003).

In Dronka, Egypt, in November 1994, heavy rain weakened the rail track causing the derailment of a train carrying fuel. The fuel leaked and was ignited by electric cables causing an explosion (Parker and Mitchell, 1995). The burning oil flowed into the village of Dronka causing over 400 fatalities (WS Atkins, 2001). A similar incident, but with less dramatic consequences took place in 1986 in San Antonio, Texas, where a flood-weakened bridge collapsed causing the derailment of a cargo train (Evening Sun, 1986). The derailment triggered an explosion in a car transporting butadiene

(Hazardous Materials, 1986). The accident injured five people and forced the evacuation of about 2,000 (Evening Sun, 1986).

Floodwater can also wash away materials stored in drums or bags or accumulate on roof tanks, leading to the collapse of the roofs. At least 28 drums containing sodium cyanide and potassium cyanide were washed in Southern France on August 29, 1983. The drums came from a chemical products warehouse in Bilbao that was seriously damaged by flooding. More than 100 50-kilogram cyanide solids and concentrated gas were washed into the North Ocean Atlantic. At least four people in the town of Bayonne were hospitalised with respiratory problems caused by the inhalation of toxic cyanide fumes.

Mitigating influences

The way dangerous chemicals are stored and adequate staff training can clearly have a critical influence on the outcome of a flood to a dangerous installation.

The flooding of a fuel distribution and storage terminal operated by BP Oil in Northampton illustrates these points. This lower tier COMAH site was flooded to a depth of 0.5 metres during the 1998 Easter Floods, however there was no loss of dangerous substances that could have reached the nearby River Nene. The entire inventory of the plant was stored in large tanks built on plinths that remained above the level of floodwater. Also prompt action by the staff prevented rainwater from accumulating on the roof of the tanks (Whitfield, 2002).

However, floodwaters can also have an important dilution effect that can help to reduce the effects of pollution caused by floods. During the Oder (Poland) floods in 1997, large agricultural and industrial areas were submerged. High amounts of nutrients were released when agricultural lands were flooded washing manure or fertilisers. Also, 56 water treatment plants were closed in Poland since they were unable to handle the large water masses causing untreated discharges downstream. However, although large amounts of nutrients and other pollutants originated at industrial sites were transported by the Oder flood, their concentrations and negative effects were not extraordinarily high due to the strong dilution (Fenske, 2001).

8.8.6 Assessment of flooding and pollution incidents

There is very little systematic research on this topic. However, statistically, it seems likely that every major installation experiences one major accident during its lifetime (Kirchsteiger, 2001) and the literature shows that flooding can initiate or exacerbate major accidents. Increased floodplain development, together with the growth of industrial activities in those areas, could contribute to a number of catastrophes

Floodwaters not only can transport pollution off site, to cause harm there, but may also cause chemical reaction or explosions when in contact with hazardous substances. On the other hand, floodwaters have an important dilution effect that reduces the contamination.

Research on health effects of flooding mainly concentrates on short-term effects. It is difficult to attribute pollution or health problems to a flood if there is no follow up to accidents involving floods and major installations.

In an attempt to provide more information on this topic, a search was undertaken of the MHIDAS data-base[21] using the search term “flood*”. As might be expected, the search generated a number of irrelevant entries (for example, “the site was flooded with firewater”). Inspection of individual entries narrowed the results to those 53 incidents presented in Appendix C which have occurred over the last 35 years.

Based on the information presented in Appendix C, it is immediately apparent that incidents involving flooding and hazardous materials rarely lead to injuries and fatalities in the surrounding population.

Although there will be varying degrees of incident capture by the database (with particular regard to the ‘rest of the world’), a review of the incidents listed provides some comments to be made.

In broad terms, there is an even split between incidents involving fixed facilities and those involving the transport of hazardous materials - as shown in Table 8.6. As would be expected, oil/chemical facilities are involved in most of the incidents involving ‘fixed’ facilities. For non-UK incidents, transport incidents predominantly involve pipelines.

Table 8.6 Incidents involving flooding and facilities by nature of facility

Nature of Facility	UK	USA	ROW	All
Oil/chemical factory/storage	3	7	10	
Waste facility		3		27
Other fixed facility	2	1	1	
Transport (pipeline)		6	10	26
Transport (other modes)	1	4	5	
All facilities	6	21	26	53

Source: Summary of data presented in Annex X.

By inspection of the incident descriptions presented in Appendix C, there are three distinct types of incident:

- water comes into contact with hazardous materials leading to a chemical reaction which may result in a fire, explosion or release of toxic gases
- flooding (or heavy rain) causes physical damage to structures (or their supports) which leads to loss of containment and release of hazardous material
- flooding leads to hazardous materials being transported outside normal containment areas.

[21] MHIDAS (Major Hazard Incident Data Service) is a database of incidents involving hazardous materials which (could have) resulted in off-site impacts operated by AEA Technology on behalf of HSE.

Each of the 53 incidents was categorised into one of these three accident types (albeit with a degree of uncertainty) and the results are summarised in Table 8.7. Although incidents involving fixed facilities comprise all types, those involving transport are nearly always due to physical damage to the transport infrastructure (such as pipeline and railway supports).

Table 8.7 Incidents involving flooding and facilities by nature of accident

	UK		USA		ROW		All	
Nature of Accident	Fixed	T'port	Fixed	T'port	Fixed	T'port	Fixed	T'port
Water leads to chemical reaction	2				4	1	6	1
Physical damage leads to release	1	1	6	10	3	13	10	24
Hazardous materials carried by floodwaters	2		5		4	1	11	1

Source: Summary of data presented in Annex X.

8.8.7 Conclusion

Based on the analysis presented in the previous sub-sections, it is apparent that there are numerous facilities located within the floodplain which, in the event of a flood, could be involved in an incident which presents a hazard to those nearby. Such incidents may involve: a direct reaction between the floodwaters and the material being handled; damage to tanks (or other items of plant) leading to a release; or the floodwaters can transport hazardous materials outside their normal containment (for example, an overflowing lagoon).

A review of past incidents indicates that the transport of hazardous materials to and from such facilities by pipeline, road, rail and ship can also present a hazard - generally, when the floodwater causes damage to the containment which, in turn, leads to the release of a hazardous material.

Although 'normal' landfill facilities are not considered to present a risk to people nearby in the event of flooding, it is possible that hazardous waste facilities (storage, treatment and disposal) may present a risk. In relation to other potential incidents, the vast majority of reported incidents involve sites (and associated transport to and from such sites) which are likely to be covered by the IPC/IPPC Regulations and/or the COMAH Regulations.

Against this background, it would seem prudent to add an additional factor to the 'area vulnerability' score in order to account for the presence of such facilities. However, it must be stressed that the significance of the associated risk (relative to the direct risk associated with the floodwaters) is likely to be low. This is borne out by the, generally, low numbers of injuries and fatalities associated with flooding incidents which involve hazardous materials. However, there will always be a low residual risk of a major incident as illustrated by the extreme events in Dronka, Egypt.

9. PEOPLE VULNERABILITY

Although the risk of flooding may be equal for all the population in a given flood-risk area, different individuals are not equally vulnerable to flood events and some will be worse affected than will others. Vulnerability is here defined as ‘characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of natural hazards’ (Few, 2003).

The vulnerability can relate to:

- The location of the victim
- The likelihood of them receiving adequate warnings
- Their ability to respond effectively to the warnings
- Their ability to survive the effects of contact with floodwater

9.1 Demographic Variables

To some extent, vulnerable people can be identified by demographic labels. The vulnerability of such individuals is derived from their lack of personal or physical resources, or from their lack of independence of action. Such people will often require special assistance at times of crisis, or special consideration in the emergency planning process (Keys, 1991).

9.2 The Elderly

Subgroups vulnerable to adverse health effects of floods include the elderly (WHO, 2002). It should be noted, however, that the term ‘elderly’ is used to describe a wide range of people, not all of whom are helpless; often the newly retired are fit and active and can cope well with the trauma of a flood (Tapsell et al, 1999, 2000). It therefore tends to be the very elderly who are most at risk from floods; the Social Flood Vulnerability Index, for instance, chose the age of 75 as the threshold for vulnerability because epidemiological research indicates that after this age there is a sharp increase in the incidence and severity of pre-existing health problems such as arthritis (Tapsell et al, 2002). According to the 2001 census, there are 3.9 million people (7.6 per cent of the population) aged 75 and over in England and Wales (ONS).

Location

US studies suggest that the elderly are disproportionately represented in hazardous areas (Adeola, 2003). It is not clear if the same is true in the UK, but Walker et al (2003) found that the financially deprived are over-represented in the tidal floodplain and there is a correlation between poverty and old age.

Warning

In the first place, the elderly may not receive adequate warning. Lack of mobility and resources can mean that many elderly people are socially isolated and have less extensive or effective social networks; they are thus less likely to receive multiple warnings from friends, family or neighbours. Research indicates that the more flood warnings people receive, the more likely they are to respond (Drabek, 1986). With respect to informal warnings, however, Thrush (2002) reports that confused elderly people may be frightened and bewildered by people hammering on their front doors to alert them to the danger.

Warning response

Once a warning is received the elderly are often frail and unable to respond without assistance (Keys, 1991), thus they are particularly vulnerable to becoming trapped in their homes. The non-institutionalised elderly are difficult to locate in situations requiring evacuation because they are not captive to a particular location and their whereabouts are not so easily known to emergency managers (Keys, 1991).

Contact with Floodwater

During a flood, the very old are more vulnerable to the effects of immersion, such as shock and hypothermia (Grieve 1959, NHS direct). Being immersed in water causes more rapid heat loss because water is 25 times more conductive than air. The very old are especially susceptible to hypothermia, because they are less able to maintain body temperature in cold conditions (NHS direct). In addition, the diseases that predispose people to hypothermia are more common in those aged over 65 (eMedicine, 2001). There is also evidence that death can be hastened by the experience of flooding, rather than somehow being caused by it (Tapsell et al, 2003).

9.3 The Long-Term Sick and Disabled

This indicator relates to those who have a limiting long-term illness, health problem or disability which limits their daily activities or the work they can do and includes problems that are due to old age (ONS). This variable is strongly correlated with old age and many of the same problems apply. Those with sensory impairments are especially vulnerable in terms of receiving and responding to flood warnings (Thrush, 2002).

Location

There is no evidence to suggest that the sick are disproportionately distributed in floodplains although, as with the elderly, long term sickness is correlated with poverty.

Warning

People with limiting, long-term illnesses are likely to have mobility problems, or may even be housebound. This will, in many cases, lead to social isolation and, as previously noted, the lack of effective community networks decreases the likelihood of receiving multiple warnings. People with impaired hearing are at particular risk of not receiving telephone warnings (Thrush, 2002).

Warning Response

Those people who suffer from illness and/or disabilities are weaker and less able to help themselves in the event of a flood warning and are more likely to need support.

Contact with Floodwater

On exposure to floodwater, many pre-existing medical conditions can increase the probability of death occurring. For instance, the increased level of physical and emotional stress that occurs during a flood can promote the likelihood of myocardial infarction and even cardiac arrest among people with a pre-existing heart condition (WHO, 2002). Some medical conditions predispose people to hypothermia; examples include pneumonia, strokes, diabetes and hypothyroidism. The mortality rate for hypothermia, in otherwise healthy individuals, is less than five per cent, while for people with pre-existing illness it is higher than fifty per cent (http://www.emedicine.com/emerg/topic279.htm).

9.4 The Financially Deprived

The characteristic of low income is associated with other vulnerability characteristics, so that areas with large numbers of people or families on low incomes are often areas where there are high concentrations of demographic groups such as single parents, ethnic minorities and the elderly (Keys, 1991).

Location

International studies suggest that the poor are disproportionately represented in hazardous areas (Adeola, 2003, Few, 2003). Recent research in the UK found that, in England, the tidal floodplain analysis shows a clear relationship with deprivation. Of the population living within the tidal floodplain there are eight times more people in the most deprived decile compared to the least deprived (Walker et al, 2003). Those who are more prosperous are typically able to exercise greater choice as to where they live than the poor (Walker et al, 2003).

Warning

Previous research has suggested a curvilinear relationship between socio-economic group (SEG) and warning response: people of high and low SEG are less likely to respond to warnings than the intermediate groups. This is thought to be a function of community involvement; the very rich and very poor tend to have less effective/extensive social networks than do the 'middle' classes and are thus less likely to receive multiple warnings (Drabek, 1986).

Warning response

It has been noted that risk-perception is not connected solely to a lack of awareness among the poor, disenfranchised and elderly. Rather, the flood risk is just one of many hazards to be reckoned with and the more common concerns of day-to-day survival can often overshadow considerations of the low-probability event, no matter how catastrophic or lethal its impact may be (Legates and Biddle, 1999 QR#116).

Long-term unemployment is embedded in some areas. With all its implications in terms of the diminution of personal resourcefulness (Keys, 1991) it is likely that the long-term unemployed are more likely to have a fatalistic outlook. People who believe that, no matter what they do, their actions cannot change their destiny, are less likely to heed, and respond effectively to, flood warnings than those with a more positive attitude (Drabek, 2000).

The financially deprived tend to lack resources that would give them independence of decision making and action, for instance, poor households are less likely to own a car than the affluent, and so might require special transport provision in the event of evacuation (Keys, 1991).

9.5 Single Parents and Children

Warning response

Lone parent families (usually female-headed) are often characterised by unfavourable adult:child ratios making evacuation, or any kind of rapid response, difficult, especially if the family is large or if the children are very young (Keys, 1991). Single parent families are, in addition, more likely to be financially deprived which increases their vulnerability (Tapsell et al, 2002).

Contact with Floodwater

Children are particularly vulnerable in any type of emergency because they are physically weaker than adults and risk being separated from their families.

The very young, like the very old, are especially susceptible to hypothermia and shock (Grieve, 1959). Compared to adults, children have an increased surface area to body volume ratio which causes them to lose body heat more rapidly (http://www.coolantarctica.com/Antarctica%20fact%20file/science/cold_hypothermia.htm).

9.6 Language and Ethnicity

Location

According to US research, minority groups are disproportionately represented in hazardous areas (Adeola, 1999). This variable is related to financial deprivation, which Walker et al (2003) found was over-represented in the UK tidal floodplain.

Warning

The status of ethnic minorities can affect them in the early planning stages; Adeola (2003) notes that minority groups are often excluded from participation in community disaster planning and preparation activities. In general, warnings are less likely to be received by minority groups. When warnings are received, they are less likely to be believed (Drabek, 2000).

Warning response

People who are unable to speak the language of the host culture will have difficulty in understanding emergency service workers in times of crisis (Keys, 1991).

9.7 Non Demographic Variables

With the exception of the homeless, people in the following categories are vulnerable purely by virtue of being more likely to be in the wrong place at the wrong time. These variables also differ from the demographic variables in that they have mostly been identified from news reports and other miscellaneous sources rather than from academic studies.

Transients and Recent Immigrants

Newcomers to an area and transients are unlikely to be aware of the threats their new environment may pose (Keys, 1991). The 19 Chinese cockle pickers who perished in the treacherous sands and tides of Morecambe Bay (BBC news) did so because they were unaware of risks that were well known to local people. Transients are generally less likely to receive initial disaster warnings from the media than residents are (Drabek, 1996).

Leisure-Related Vulnerability

The leisure-related vulnerability referred to here is different to the recreational use of floodwaters described in the self imposed risk section. With respect to self imposed risk, the victim increases their risk by actively and intentionally engaging with the floodwater. Leisure-related vulnerability, however, is passive and unintentional. Water-sports activities are obvious examples. According to RoSPA figures, 146 (54 per cent) of behaviour-related drownings in the UK in 2001 were related to leisure activities such as angling and canoeing.

Seasonal tourists occupy many hazardous regions (Cutter, 2003). Camping or caravanning holidays in flood-risk areas are an obvious example; camping sites and caravan parks are often sited in attractive riverside or coastal locations. During the Easter floods of 1998, 46 people were evacuated from a caravan park in Abbots Salford, Worcestershire and a man was drowned in a flooded caravan site near Evesham, Worcestershire (BBC news). The lack of shelter provided by tents and caravans are another factor which puts holiday makers at risk.

9.8 Non Demographic Variables: The 'Roofless' Homeless

The term 'homeless' covers a variety of situations, such as people living in bed and breakfast accommodation or those living in overcrowded conditions. However, this vulnerability indicator refers specifically to 'rooflessness' (also known as street homelessness or rough sleeping) where people have literally nowhere to stay and are forced to sleep on the streets or elsewhere outside (Shelter, 2001). There is no evidence to suggest that rough sleepers are preferentially distributed in hazardous areas (Shelter spokesman, pers. comm).

Those sleeping rough can be difficult to locate; the government only systematically collects statistics on those homeless people who have applied to local authorities for help – these are usually families with children, single people are not generally entitled to help unless they are deemed to be 'especially' vulnerable. There are no comprehensive national figures on the extent of single homelessness (Shelter, 2001). Instead, 'rough sleeping' counts are conducted by local authorities in partnership with local homeless agencies, in order to provide a snap-shot of the number of people sleeping rough in a given geographical area on a single night (ODPM).

Flood warning

The homeless are unlikely to receive formal flood warnings. In addition, the homeless will not have access to the information and resources that the more fortunate take for granted (Shelter nd).

Contact with Floodwater

Many rough sleepers suffer from acute health problems, and generally have a higher incidence of diseases such as TB and hepatitis than the general population (Crisis nd, McMurray-Avila et al, 1998). The homeless are also more likely to suffer from chronic chest or breathing problems and musculoskeletal problems (Joseph Rowntree Foundation, 1994). They may also suffer from serious mental illnesses such as schizophrenia, and may have problems with drug and alcohol dependency (Shelter 2001). Many rough sleepers will have a combination of these health issues (Shelter nd) making them very vulnerable to the effects of immersion.

9.9 Non Demographic Variables: Work-Related Vulnerability

The vulnerability in this instance is based on the occupations of the victims. Research in Australia suggests that work-related fatalities account for 12.4 per cent of known flood fatalities and cites farmers and postal employees as examples of workers that may be at risk (Coates, 1997). However, these workers have not actively sought to place themselves in a flood-prone area as a fundamental part of their jobs; the risk is imposed on them by external factors. As a vulnerability indicator, we are looking at occupations where the flood-risk is intrinsically embedded in the employees' jobs.

Those who work in the emergency services are the most obvious examples, such as the firefighter who died after attempting to rescue a couple trapped in their car during the flash flooding in France in 2002 (The Scotsman), and the firefighter who was sucked into a culvert while attempting to reach a stranded motorist in Illinois, USA (NOAA). However, local authority workers are also at risk, they may be employed in clearing culverts, like the two men who were swept away and drowned while cleaning a storm drain in Tennessee in 2002 (NOAA) or other work such as the workmen building a sandbag barrier who were swept down the road in the Uphill flood of 1981 (Green et al, 1985).

In all these cases, the very nature of the victims' jobs directly increased the risk to the individual. There could be many more occupations that may actively put their practitioners at risk, even academic researchers are not immune; in 1999 a USGS employee attempting to take flow measurements on the Souris River, North Dakota, was drowned (NOAA).

9.10 Mapping People Vulnerability

Those vulnerable people that can be identified by demographic labels can be identified using the 2001 census. The Office of National Statistics (ONS) supplies data on population age, lone parents, and limiting long-term illness at the level of output areas (the smallest unit of census geography). Those who do not speak English, or for whom English is a second language are more difficult to quantify, however the ONS statistics on country of birth (Table UV08) and also ethnicity (Table UV09) may be useful in identifying areas where English is unlikely to be the first language of the inhabitants. Financial deprivation is also harder to identify than, for instance, age. Table UV50 (approximated social grade) is a potentially useful source, as is Table UV67 (households by selected household characteristics).

Crude percentages of these variables could be transformed, normalised, and incorporated into a compound additive index (see for example Tapsell *et al* 2002 and Townsend *et al* 1988). The vulnerability of the inhabitants of any output area could then be assessed by comparing its score against the national average. (The calculation of the Social Flood Vulnerability Index (SFVI) that is used in the Modelling and Decision Support Framework (MDSF) Catchment Flood Management Planning tool is described in Appendix 2).

Ideally the nationally available census data would be replaced or supplemented by local authority data which should be more detailed and reliable. Those people receiving a social service such as home care, meals on wheels etc could be included within the appropriate category of vulnerability.

In theory, it should be possible to construct a vulnerability index from the demographic variables, whilst allowing for the non-demographic variables to be 'plugged in'. This could be done, for example, by using a sliding scale from 0 to 10 according to estimates of homeless people, tourists etc in the flood-risk area.

It should be possible to obtain some information on the location of homeless people from local authority departments and from voluntary organisations. The location of caravan and camping sites should also be available from local authorities. However, there is a clear need for better temporal and spatial estimates of tourists, homeless people, and transient – possibly undocumented – workers (Cutter, 2003).

9.11 Possible Future Work

- To create a people vulnerability index from nationally available census data: the "Framework" Index.
- To explore methods of supplementing national census data with local data to improve the accuracy of the index: The "Local context".
- To explore methods of mapping both the "Framework" Index and the "Local context" at the same time
- To explore methods of 'plugging in' non-demographic variables to further refine the index.

We envisage that the output database would have two fields; one field would quantify the vulnerability of a particular area from national census data, the other field would be populated by local-level data.

Risk to life and human behaviour ("self-imposed risk")[22]

Human behaviour in disaster situations can create self-imposed risks. According to the World Health Organisation estimates, 40 per cent of the health impacts of floods are directly related to 'wrong' behaviour (WHO, 2002). This behaviour is often seen as 'irrational', although this may not in fact be the case (Ramsbottom *et al*, 2004). The reality is that little is known about the motivations and thought-processes that lead to these 'irrational' actions.

9.12 A typology of incidents

The following is based on the human behaviour typology devised on the basis of experience in the river Oder floods of 1997, although some amendments have been made.

Taking that typology, we have made the addition of 'rescue behaviour', which includes people who put themselves at risk trying to rescue their pets. Originally, this was included as an aspect of 'asset retrieval', but it seems doubtful that people try to rescue their pets because they see them as assets with monetary value. Rather, people seem to rescue their pets (although perhaps not livestock) for much the same reason as they will try to rescue a child, or even an adult stranger. We have also amended 'people being trapped' to 'people being trapped in cars', because being trapped at home is not a self-endangering 'action' as such; unless evacuation is to take place; people are supposed to stay in their homes during a flood. We have omitted the example of the homeless people trapped in an underpass because this seems to be more to do with people vulnerability than it is with self-imposed risk.

Four behaviours that can increase an individual's risk are therefore proposed:

- Behaviour related to asset protection and/or recovery
- Behaviour related to the excitement of major floods
- Behaviour related to people driving motor vehicles
- Behaviour related to trying to rescue people or pets.

These self-endangering activities are discussed in more detail below.

9.12.1 Behaviour related to asset protection and/recovery

This behaviour entails either trying to retrieve goods left behind in homes, or remaining at home, despite calls for evacuation, due to fears of loss of assets. This behaviour must arise from misperception, or ignorance, of the risks; people simply underestimate the power of flowing water and the speed with which a life-threatening situation can arise. Otherwise it would be impossible to explain incidents such as the old man in New South

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Wales, Australia, who drowned in 1870 when his boat capsized as he was trying to retrieve a pumpkin (Coates, 1999).
The fear of losing possessions, either through the effects of floodwater or the actions of looters, can deter people from heeding evacuation calls. During flooding in Poland, in 1997, many people refused to evacuate because they were unwilling to leave their possessions untended (Rosenthal and Bezuyen, 2000). The worry that their possessions may not be secure may also lead to fatal delays in people's response; in Dresden, Germany, in 2002, a man drowned in his basement, which he was checking a final time before evacuating (Beststar.com/news). Attempts to protect assets by trying to prevent water entering the property, for instance by wedging towels or blankets underneath doors, are not only futile, but can also cause delays at what may be a critical time (Tapsell and Tunstall, 2001).

People appear to make their decisions here based on the perceived value of their assets, rather than the risk to their own life. However, this behaviour may be an aspect of 'normalcy bias' whereby people under stress tend to interpret new data in terms of the known and the familiar (Drabek, 1986). It may be that the prospect of losing possessions is familiar, and therefore within the scope of people's experience; the consequences of the loss are known, or are easy to imagine, while the risk to life from floodwater is unknown and may be difficult to imagine. Thus, the two men who drowned trying to save their parked cars from going under water in a garage in Berlin (CNN news) may have asked themselves "what are the consequences of me losing my car?" rather than "what are the risks of me getting killed if I try to retrieve my car?". Such behaviour was not because they cared more about their cars than their lives, but because the first question is a familiar one which they could answer.

9.12.2 Behaviour related to the excitement of major floods

Within a short period of time after a disaster strikes, numbers of sightseers make their way to the disaster area in a phenomenon known as 'mass convergence' (Rosenthal and Bezuyen, 2000). The behaviours of these 'disaster tourists' can be classified as being passive, spectator activity or active involvement with the floodwaters. The passive spectator activity seems to apply to a broad cross-section of people. Judging by the available information, this is the only self-endangering behaviour that is just as likely to be adopted by women as by men.

There is a difference between curious citizens, wanting to witness an exciting event, and offers of help from rescue workers and volunteers (Rosenthal and Bezuyen, 2000). However, sometimes the distinction is not as clear-cut as it perhaps should be. Following an earthquake in Gujarat, India, a surgeon working at a local hospital noted that:

> *"It was horror tourism at its best. Doctors arrived in hordes, carrying video equipment to capture the graphic display of misery and show them back home. That was an end in itself… These fly-by-night operators insisted on operating and were gone with their photographs within two hours after surgery, leaving us to take care of their handiwork. The lack of accountability was remarkable."* (www.onlinevolunteers.org/relief/mfc-tourism.html)

This extract makes the point that the attraction of a major disaster is not confined to the ignorant and ill-educated – the educated and intelligent are just as likely to want to 'see the sights'. So it would appear that people might combine disaster tourism with their 'helping' activities. The doctors in the above incident were not only a liability to the recovery process, rather than a blessing, but could conceivably have become casualties themselves. In general, however, doctors, like journalists and rescue workers, are at least doing their job.

Even the journalists who were described as having 'descended like ghouls' on Essex following the great tidal flood of 1953, interrupting the work in hand and monopolising precious telephone lines (Grieve, 1959), can broadly be said to have been acting in the public interest. The same cannot be said for the curious citizens that converge on a disaster area, hindering rescue operations and/or putting their own lives at risk. For instance, people ignored warning signs in order to enter forbidden areas in the west European floods of 1993 and 1995 (Rosenthal and Bezuyen, 2000). Following the Easter floods of 1998 in the UK, police also complained that sightseers, keen to witness the effects of the disaster, were hindering their work (BBC news).

The phenomenon of active participation with the floodwaters seems to be the province of children and adolescent males. A study in Australia found that 5.7 per cent of known fatalities occurred through some attempt at recreational use of the floodwaters (Coates, 1999). Children are especially vulnerable to the excitement of fast-flowing water; they have little or no sense of 'risk', as adults understand the term. According to the Royal Society for the Prevention of Accidents (RoSPA), drowning is the third most common cause of accidental death among the under 16s, although it should be noted that this figure may include deaths in ponds and swimming pools.

Children who drown are often victims of their own misjudgement of their swimming ability. RoSPA figures show that more than half of those children who drowned could in fact swim (RoSPA, 2003). In January 2004, a 12-year old boy died in south Wales after he and three friends fell into the River Ebbw; it is thought that they had been playing on the rain-swollen river on a makeshift raft (BBC News).

Young adolescent males' sense of personal danger can seem only slightly (if at all) better developed than is a child's. The adolescent male who was sucked into a storm-water drain in Brisbane, Australia, when surfing on the floodwater on a boogie board (Coates, 1999) could have had little appreciation of the risks involved, likewise the swimmer who 'challenged' the flood-swollen river Oder in 1997 by trying to swim across it (Kundzewicz, 2004). The poorly developed sense of risk among adolescent males is exacerbated when alcohol is involved. According to RoSPA figures for 2001, 94 (37 per cent) of the 256 'activity-related' drownings in the UK involved alcohol. A US study of drownings in Sacramento County, California, found that males in the 15-19 age group had a high drowning rate, and 38 per cent of fatalities in that age group were alcohol related (Wintemute *et al*., 1987).

In the Netherlands and Germany there were even special organisations offering tours through flooded areas, including snorkelling into flooded homes following the floods of 1993/1995 (Rosenthal and Bezuyen, 2000). This raises the issue of people exploiting a disaster, or exploiting disaster tourists themselves, for economic gain. Where there are crowds, there may well be people trying to sell them hamburgers, coffee or whatever. These activities conceivably encourage more people to join the spectators.

9.12.3 Behaviour related to people driving motor vehicles

More than fifty per cent of flood-related drownings in the US occur when a vehicle is driven into hazardous floodwaters. According to NOAA figures, there were 450 flood fatalities in the US between 1998 and 2003 and 253 (56 per cent) of these were considered as being vehicle related (NOAA, 2004).

However, these figures should be treated with caution. When looked at in detail, some drivers had clearly made a wrong decision that cost them their lives, such as instances where the driver ignored warnings and/or drove around barriers. Yet it is by no means clear that all of these incidents were the fault of the driver. Many of the deaths seem to have been tragic accidents that just happened to have involved cars. Many others were inconclusive, the circumstances of the death described as being 'vehicle-related' or something similarly vague.

People do not want to leave the warmth and perceived security of their cars, trucks or boats, and can easily be trapped inside (CDC, 1994). This may reflect motorists' misconception that cars can provide adequate protection from rising or swiftly moving floodwaters – a perception that can, unfortunately, be reinforced by media images of dramatic rescues (Gruntfest, 1996). In fact, vehicles driven into floodwater become more buoyant because the momentum of water is transferred to the vehicle (WHO, 2002). Even if roads are closed, people may drive around the barriers (Gruntfest, 1996). Like the 'asset retrieval' activities described above, this behaviour arises through misperception, or ignorance, of the risks involved. Also, in common with 'asset retrieval' activities, there could well be an element of normalcy bias in this behaviour; the desire to continue with ones routine, and reach ones destination (coupled with the desire to remain in a warm, dry, 'safe' environment) is stronger than the perceived risk posed by the floodwater.

However it should be said that not all drivers could necessarily be expected to know the risks of driving through floodwater. This is especially true if they do not live in a flood-risk area themselves. The danger of driving through floodwaters is not widely publicised in the UK. The Highway Code, for instance, does not give advice on avoiding flooded roads, and there is no easily accessible information on the Environment Agency website, so a motorist who inadvertently drives into a flood stricken area does so in ignorance of the risks.

In this respect a recent incident seems typical of the behaviour of the non-aware driver. In February 2004, three men had to be airlifted from their van after they became stranded in five feet of rising water near a river in Conwy Valley, Wales (BBC news). Fortunately, the men were unharmed.

9.12.4 Behaviour related to trying to rescue people or pets

The great tidal surge flood of 1953, which devastated the East Coast of England and in which 307 people died, saw many acts of selfless heroism. It seems that in times of extreme stress there is a reservoir of courage and selflessness in people which is brought out under the levelling circumstances of a disaster (Pollard, 1977). Unfortunately, members of the public, unlike the emergency services, are unlikely to have the training or the resources necessary to rescue someone without endangering themselves, and it is this feature of rescue behaviour that increases the risk to the individual. The following is an excerpt from an interview with a victim of the floods that affected north east England in June 2000 (Tapsell and Tunstall, 2001) who should consider himself lucky to still be alive.

> *"... I had to swim from the corner shop up to the bungalows where my Aunt lives and an old man had fallen, there was a wall, obviously you couldn't see the wall because of the water and he'd gone over the wall and he went under and I had to swim from the corner shop to get him. ... and then my auntie, she'd gone under, they were on their way over to get my other auntie out of the bungalow, and I mean she's a strong swimmer really but she was going under all the time, it was that forceful was the water, and it was freezing cold and dirty."*

People can be very emotionally attached to their pets and may go to extraordinary lengths to rescue them from danger. According to RoSPA over fifty per cent of ice-related drownings involved an attempted rescue of another person or a dog (RoSPA, 2000). As an indication of the strength of the urge to save animals in distress, in January 2004 the coastguard warned dog owners to keep a tight leash on their dogs. This was because coastguard rescue teams always respond to calls about dogs in distress in case the owners (or bystanders) put themselves at risk by trying to rescue the dogs themselves (Maritime and Coastguard Agency, 2004).

During the 1953 flood many cases were reported of flood victims arriving at rescue centres clinging to their cats, dogs and caged birds. Many pet owners, who had been successfully evacuated, fought their way back through the flood to find their animals (Grieve, 1959).

9.13 'Self-imposed risk' and gender

From the literature and examples examined, it appears that men are more likely to adopt most of these self-endangering behaviours than are women; males simply tend to take more risks than females (Coates, 1999).

In a study of Australian flood fatalities from 1788 to 1996, it was found that 80 per cent of victims were male (Coates, 1999). Statistics on US flood deaths from 1997 to 2003, compiled by NOAA, reveal that of the 408 fatalities where gender was recorded, 266 (65 per cent) were male (NOAA, 2004).

Coates (1999) noted that Australian fatalities caused by trying to retrieve assets were almost exclusively male. The recreational use of floodwater, as mentioned above, seems to be an activity dominated by adolescent males. With respect to rescue behaviour, Drabek (1986) observes that men are more likely than women to help strangers and will remain with rescue activities for longer.

Traditionally, men have also tended to have more exposure to the elements (Coates, 1999), either by virtue of their occupations or their leisure activities. They are thus more likely to witness events where another person gets into difficulties and, therefore, more likely to attempt a rescue. As mentioned earlier, it seems that the only self-endangering behaviour which women are as likely as men to adopt, is the ‘passive spectator’ type of disaster tourism.

9.14 Assessment: Risk to life and human behaviour (“self-imposed risk”)

Loss of life and serious injury during floods that results from aberrant human behaviour appears to be all too common and one of the major causes of loss of life and injury in flood events. This behaviour appears to arise from inadequate prediction of the risks involved, rather than from a calm analysis of risks versus rewards from such behaviour. However, people can only behave ‘rationally’ according to the information they have, and this information may be incomplete or incorrect. For example (as mentioned above) the risks of driving through floodwater are not widely publicised in the UK.

There appears to be a strong gender bias, with these risks being taken more often by males than by females, and a bias towards the young (the old are perhaps wiser, and more aware of their inherent frailty vis-à-vis the floodwaters).

10. OTHER ACTIVITIES

Tolerable risk

There is ongoing work being undertaken by RPA for the Agency on developing risk-based criteria to determine the acceptability or otherwise of risks to people associated with new developments in flood risk areas. This work will be reported on in due course and the results will be incorporated into the Risks to People methodology.

Consultation

There has been one further consultation meeting between the project team and key stakeholders that clarified the guidance required from the project and information that would support guidance produced by other projects, particularly the Agency and Defra project FD2320 on Strategic Flood Risk Assessment.

Dissemination

The project team presented aspects of the Risks to People project at a Thames Estuary 2100 workshop in September 2004. The project has been invited to present a paper on flood hazards behind defences for the CIWEM conference in January 2005 and have submitted an abstract for the Defra conference in July 2005.

GIS data sources and Risks to People examples

We have prepared example Risks to People maps for the coastal example of Towyn, North Wales and the Thamesmead area of the Thames Estuary. A mapping process and one further example is in preparation but there needs to be further discussion on the nature of the People Vulnerability index and refinement of the overall methodology before these are presented.

Links with other projects

The linkages between Risks to People were described in Interim Report 1. The project is now strongly linked with Agency/Defra project FD2320 on Strategic Flood Risks Assessment and it is likely that this project will take forward elements of the Risks to People research to produces tools and guidance for planners. There are also strong links with RASP regarding risks behind defences and the forward work programme of FloodSITE (www.floodsite.net).

11. CONCLUSIONS

11.1 Main conclusions

This report describes research in progress on the Flood Risks to People project. The Flood Hazard Rating work is now complete.

To summarise the conclusions that were given in Section 7.13:

- The proposed hazard rating is (v+1.5) x d
- Threshold values for different levels of risk have been estimated
- The impacts of debris and building collapse have been discussed and will be taken into account in the refined methodology
- Relationships have been developed to estimate the hazard rating behind a defence from overtopping and breach
- A methodology for including violent wave overtopping is introduced.

Further refinement of the overall method and selection of the final Risks to People equations is scheduled under the task "Review and Enhance Method" programmed between August and November 2004.

The research on Area Vulnerability is ongoing but a number of preliminary conclusions can be drawn from the work completed to date:-

- The overall method is likely to remain unchanged from Phase 1
- It is possible to link Agency information on flood warning effectiveness with the simple three point score of flood warning (Table 6.3, see also Section 8.4.6)
- The impacts of land use planning are less clear. At a high level different policies, e.g. related to the type of housing, can be linked to the "nature of the area" criteria used for scoring Area Vulnerability
- Investment in flood defence will directly effect flood hazard but may also influence the "speed of onset" criteria used for scoring area vulnerability.

The research on People Vulnerability is in its early stages. The research to date suggests:

- There are four behaviour categories that increase an individual's risk (see Section 9.12)
- The behaviour that increases risk occurs due to misperception or ignorance of the risks
- Behaviour to increase risk is not unique to the ill-educated and ignorant- the well educated and intelligent will increase their own danger as well
- Men are more likely than women to demonstrate behaviour that will put themselves at risk.

11.2 Outputs

The outputs from the project are as follows:

- **Flood hazard rating**, which will be used for flood hazard mapping and contribute to the overall flood risks to people methodology
- Analysis of the **effectiveness of flood warning**, which will contribute to the overall flood risks to people methodology
- Analysis of the **effectiveness of flood defence regulation**, which may contribute to the overall flood risks to people methodology if this can be supported by suitable evidence/data
- Scoping study on the **impacts of water quality** on flood risks to people, which may contribute to the overall flood risks to people methodology if the impacts are shown to be significant
- Analysis of the **impact of human behaviour** on flood risks to people, which will contribute to the People Vulnerability component of the overall flood risk to people methodology
- Development of a People Vulnerability Index, which will contribute to the overall flood risks to people methodology
- Revised **Flood Risks to People Methodology**
- **Estimate of uncertainty** associated with the outputs of the flood risks to people methodology
- **Guidance document** on flood risks to people
- Summary document providing **information for other relevant research projects** on flood risks to people
- Summary document providing a **recommended approach to flood hazard and vulnerability mapping**.

The key outputs are the flood hazard rating (including guidance on application), the method for calculating flood risks to people, and the Guidance document. The likely needs for these key outputs by end users are summarised in Table 11.1 below.

It is also expected that the project outputs will make important contributions to a number of ongoing developments in flood management as the significance of flood risks to people increases both in appraisal and planning. The links between flood risks to people and other relevant research and development activities are summarised in Appendix A.

Table 11.1 Applications of key outputs

Activity (and relevant organisation) Note: 'Agency' is the Environment Agency	Key outputs from Flood Risks to People project			Scale of outputs (see Table 6.9 for discussion of data at different scales)
	Flood hazard rating	**Method for estimating flood risks to people**	**Guidance on flood risks to people**	
Appraisal (Defra)		✓		Outputs may be based on national, regional and local data, depending on level of appraisal.
Flood Mapping Strategy (Agency)	✓	Not required at present		National flood hazard mapping planned.
Flood Warning (Agency)	✓	✓	✓	Outputs should be based on regional or local data. **Pilot test site**
Emergency planning and response (Local Authorities, Police)	✓	✓	✓	Outputs should be based on local data
Flood awareness (Agency)	✓	✓	✓	Outputs should be based on local data
Flood defence regulation (Agency)	✓	Not required	✓	Outputs should be based on regional or local data
Land use planning (Local Authorities)	✓	Not required	✓	Outputs should be based on regional or local data
Flood plans for reservoirs (Agency)	✓	✓		Outputs should be based on local data
Thames embayments project	✓	✓		**Pilot test site:** Outputs will be based on local data

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Zhai, G., Fukuzono, T. and Ikeda, S.

13. APPENDICES

Appendix A

Table A-1 Key links between the Flood Risks to People project and other R&D

Project or Initiative	Ref	Complete	Ongoing	Future	Comments
Risk assessment for flood and coastal defence for strategic planning (RASP)	W5B-030		✓		RASP includes flood defence data (condition and "fragility" curves), population and social vulnerability data that can be applied for regional and national "Risks to People" mapping. The Risks to People approach can be applied to future versions of RASP.
Fore*sight* flood and coastal defence project		✓			One outcome of Foresight was the need to understand the **risks to people** rather than simply location within the floodplain. The project methodology can be incorporated into any future Foresight work.
Investigation of extreme flood processes and uncertainty (IMPACT)		✓			Investigated the impacts of dam burst including the development of risk and evacuation models.
Risk management for UK reservoirs	CIRIA C542	✓			Flood Risks to People can provide more information on risk than basic flood mapping. Flood plans will be required for all Category A Reservoirs. The Agency wish to use the Flood Risks to People methodology in the development of Flood Plans (contact: Ian Hope).
Catchment Flood Management Plans (CFMPs)			✓		The appraisal method adopted in CFMPs will be Multi-Criteria Analysis, and one of the criteria will be contribution to public safety and reducing social vulnerability (hence risks to people). The results of the project will therefore be used at a high level to assess risks to people in

Project or Initiative	**Ref**	**Complete**	**Ongoing**	**Future**	**Comments**
					catchments.
Flood mapping strategy			✓		The Agency's Flood Mapping Strategy includes the mapping of flood hazard. The output from the Flood Risks to People project will contribute directly to this mapping requirement. It may also be possible to extend national mapping to include flood risks to people if the case can be justified (contact David Murphy).
Flood risk assessment for new development	FD2320		✓		*People at risk rather than floodplain zones. Risks to People maps can provide information to support planning decisions at a range of scales.*
Modelling and Decision Support Framework (MDSF)			✓		The MDSF is a system for supporting decision making at catchment/coastal zone and Strategy Plan level. It is likely that the Multi-Criteria Analysis used for CFMPs and SMPs will include risks to people (see discussion under CFMPs above). To support decision making for CFMPs and SMPs it is therefore likely that the flood risks to people methodology will be included in the MDSF in the future.
Performance and reliability of flood and coastal defence structures	FD2319		✓		Will provide information that could be used to refine the Flood Risks to People methodology.
Sustainable flood and coastal management	FD2015		✓		Sustainable approaches are more "people centred" and therefore it is important to understand risks to people and vulnerability. Risks to People methodology may provide information on how management interventions such as regulation can reduce the consequences of flooding.
Flood risk management research consortium				✓	Approaches developed in Flood Risks to People are relevant to the Stakeholder and Policy and Risk and Uncertainty themes of this new

Project or Initiative	Ref	Complete	Ongoing	Future	Comments
					research programme.
Integrated flood risk analysis and management methodologies (FLOOD*site*)				✓	This is a major 5 year EU project led by HR Wallingford. The Environment Agency are partners in the project and there will opportunities to develop the Flood Risks to People approach as part of its work in "integrated strategies and tools to assess and mitigate flood hazard, vulnerability and risk"
Thames embayments			✓		This project is developing models for flood warning and flood defence appraisal in the areas defended by the tidal Thames embankments. This work can be used in conjunction with the Flood Risks to People project to assess the risks to people in these important defended areas. **Thames Region wishes to pilot test the Flood Risks to People methodology on the Thames embayments (contact: Kevin House).**
Flood hazard for flood warning purposes				✓	The Environment Agency recognises that the Flood Risks to People project will provide new information for the targeting of flood warnings, particularly in the identification of areas where there is a high risk to people (but flood warning cannot be justified on economic grounds). **The Environment Agency wishes to pilot test the Flood Risks to People methodology for flood warning purposes (contact: Tony Andryszewski).**

Appendix B

Terms of Reference

Abstract of the Research:

The main objective of the research is to develop a method of estimating flood risks to people that is suitable for assessing and mapping the risk of death or serious harm to people as a result of flooding. This proposal covers the R&D needed to develop the method based on the findings of the Phase 1 study including the findings of user needs from the Project Board meeting at the end of Phase 1.

The R&D in Phase 2 includes:

- Consultation with key personnel at Defra, the Environment Agency and Local Authorities in order to develop and disseminate user-oriented research
- Refinement of the flood hazard rating proposed in Phase 1, based on flow velocity, flood depth and water quality (particularly debris potential)
- The effectiveness of flood warning, regulation and emergency planning/response in reducing flood risks to people
- The impact on flood risks to people of the behaviour and vulnerability of people during floods
- Refinement of the overall method proposed in Phase 1
- A method for assessing the uncertainty and confidence limits associated with the results
- A guidance document on assessing and managing flood risks to people
- Provide a basis for the Agency's Flood Hazard and Vulnerability Maps
- Provide information related to risk of death and serious physical injuries to people by flooding, for on-going research and their improvements (e.g. MDSF, RASP, PAMS and Flood Foresight).

Purpose

The purpose of the research is to enable Defra and the Environment Agency to identify the locations where there is a significant risk of loss of life or serious harm to people as a result of flooding. Phase 1 of the project identified in outline the relationships between causal factors and the impacts on people, and proposed a method for assessing flood risks to people. This research is needed to:

- Consider user needs
- Refine the input parameters to the assessment method
- Refine the overall assessment method
- Disseminate the method to targeted users to use for policy decisions and process.

Scientific context

An aim of the Government's Flood and Coastal Defence Policy is to reduce risk to people and it is a priority area of the Defra/Agency Joint research (ROAME A Statement – Theme 5). Information about flooding is widely available on the Indicative

Flood Plain Maps, and these existing maps can be classified as suitable for screening/identifying areas subject to flooding. However, further effort is needed to combine these maps with an indication of the risk to the people/property/infrastructure and the environmental interests located in the flood plain/erosion zone. It would provide rapidly assimilated identification of "hot-spots" for concentrated action by related authorities and functions (e.g. flood warning, development control, improvement and emergency response). This is also in line with the Agency's desire to move towards publication of flood risk (as opposed to flood plan) maps.

Flood risk to people is highly dependent on flood hazard characteristics such as depth, duration, velocity, and water quality (including debris). These characteristics vary according to several factors such as geo-morphology, hydrogeology, land use (rural and urban including forestry and industry) and the type of flooding, etc. The type of flooding can be "sudden onset" or "seasonal saturation" under fluvial, tidal or coastal conditions. The correlation between flood hazard and flood risks to people is likely to be higher for "sudden onset" events than "seasonal saturation" events. Other social and physical factors also contribute to risks to people, for example type of housing.

The losses or impact of flooding on the people (harm) can be categorised as "Direct" or "Indirect" Losses as a result of level of physical contact or connection with the floods. These losses can be grouped as "Tangible" or "Intangible", depending on whether or not these are capable of assessment in monetary value, These can be further sub-divided into "Primary" and "Secondary" categories depending on the nature of the losses.

With regard to impacts on people, these losses are "Intangible" and can be categorised as follows:

Direct	-	Primary	-	Loss of human life
	-	Secondary	-	Ill-health of flood victim
Indirect	-	Primary	-	Increased hazard vulnerability of survivors
	-	Secondary	-	Out-migration and reduced confidence in the area.

R&D is already in progress on ill-health of flood victims. The proposed R&D will provide a method for assessing conditions where loss of life or serious harm to people could occur, and will recommend best practice guidance to managing this risk. It will also include advice on how this risk to people could be mapped.

Scientific Objectives

1. Consultation with key stakeholders at Defra, the Environment Agency and Local Authorities to develop and disseminate required outcomes.
2. To refine the definition of hazard rating developed in Phase 1 of the project, in which the flood hazard is related to depth and velocity of floodwater.
3. To assess the effectiveness of flood warning, regulation and emergency planning/response in reducing flood risks to people.
4. To assess people vulnerability and the impact of social behaviour on flood risks to people.
5. To refine the overall methodology proposed in Phase 1, taking account of the results from objectives 1, 2, 3 and 4 above.

6. Further testing and refinement of the methodology using a wider range of case studies.
7. To provide guidance on assessing the uncertainty and confidence limits associated with the overall methodology.
8. To produce a guidance document on assessing and managing flood risks to people related to death or serious harm.
9. To provide a basis for Agency's Flood Hazard and Vulnerability Maps.
10. To provide information related to risk of death and serious physical injuries to people by flooding, for on-going research and their improvements (e.g. MDSF, RASP, PAMS and Flood Foresight).

Interdependence of Objectives

The successful completion of scientific objectives 1, 2, 3 and 4 is essential to achieve the key objective of developing a methodology for assessing flood risks to people (scientific objective 5). Scientific objectives 6 and 7 are dependent on completing scientific objective 5. Scientific objectives 8 to 10 are outputs for different uses and therefore depend on the outputs from objectives 1 to 7.

Factors which might cause delays

The degree to which scientific objectives 1, 2, 3, and 4 are achieved depends to a large extent on the availability of information including literature and the experience of consultees (particularly Defra, Environment Agency staff involved with risk, forecasting, flood warning, strategic planning and regulation, and Local Authority emergency planners). It will be important to validate scientific objective 6 against observed data, but it may be difficult to find sufficient detailed data for UK floods. Without such data, the degree to which the method can be refined will be limited.

Approaches and Research Plan

A number of items of research were identified in Phase 1. These are listed and prioritised below
:

Priority 1 Essential to achieve the overall purpose of the project

1. Consultation with key stakeholders at Defra, the Environment Agency and Local Authorities to develop and disseminate required outcomes.
2. Refine the definition of the flood hazard rating.
3. Further testing and refinement of the methodology using a wider range of case studies.
4. Risk assessment and management guidance document on flood risks to people.
5. Provide information related to risk of death and serious physical injuries to people by flooding, for on-going research and their improvements.

Priority 2 Potential improvements to the method to meet specific needs of users

1. Effectiveness of flood warning, regulation, emergency planning and emergency response.

2. Scoping Study on the impacts of water quality during flooding on risks to people (physical pollution from land use, for example debris and mud flow, chemical pollution from industry, and biological pollution from sewage treatment plants, etc.).
3. Behaviour of people during floods.
4. People Vulnerability Index.
5. Uncertainty in the results and confidence limits.
6. Provide a basis for Agency's Flood Hazard and Vulnerability Maps.

Priority 3 Other potential improvements to the method

1. Improvement of the methodology using detailed modelling.

Priority 4 Items needed for the flood mapping method

1. Mapping method for the flood hazard rating.
2. Specification for GIS based mapping method.
3. Trial implementation of GIS based mapping method.
4. Pilot testing of the GIS based mapping method.

Priorities 1 and 2 have been selected for implementation under Phase 2 of the project. The approaches to these twelve items are outlined below.

1 Consultation

There will be a period of consultation at the start of the project to understand user needs and establish contacts between the project team and the users. The users to be consulted will include representatives from Defra, the Environment Agency and Local Authorities. It is hoped that a group of representatives of stakeholder groups will be established, who will be consulted as the work proceeds and asked to review the outputs. It is also expected that the stakeholder group will advise on routes for dissemination and possibly assist with the dissemination process.

2 Flood Hazard Rating

The purpose of this approach is to develop the relationship between loss of life/injury and the principal relevant factors such as flow velocity and flood depth and any other factors that are a direct cause of loss of life/injury during and immediately after floods. Phase 1 developed a framework and a preliminary method to test and illustrate the concepts. This Phase will evaluate a wider range of existing data (both laboratory and field scale), carry out limited additional experimental work, and will provide a refinement of the hazard rating in which we can have more confidence. The following research will be carried out:

- Detailed review of previous research taking particular account of the "realism" of experimental work, and the interpretation of data;
- Development of a simple mathematical model of stability of people in floodwater, to provide a means of extending the hazard rating to extremes that cannot be simulated physically for safely or other practical reasons;
- Limited experimental work in order to fill gaps in data; and
- Use of the results from the above work to refine the hazard rating.

The refinement of the hazard rating will take account of the findings of the debris Scoping Study under Item 4 below.

The approach will also consider the link between hazard rating and building collapse, and how this should be incorporated in the method. Specific types of buildings that are particularly prone to collapse during floods include chalets, caravans and other lightweight structures.

3 Effectiveness of flood warning and other activities such as regulation and emergency planning

The purpose of this approach is to consider the effectiveness of flood warning systems in reducing flood risks to people, in order to support the development and design of flood warning, awareness-raising and educational activities.

The effectiveness of flood warning systems (including regulation and emergency planning and preparing for floods) is currently included in the area vulnerability score in the Phase 1 methodology. This is not required for all assessments and this issue will be reviewed, possibly giving a more modular approach where the flood warning component is only included in the assessment if necessary.

The research will consist of a historical review of effectiveness of flood warning, flood prevention regulation and emergency planning including interviews with key players in Agency, Local Authority and Defra. The results will be used in the overall refinement of the method in Approach 6 below.

4 Impacts of water quality (e.g. debris) on risks to people

This Approach will carry out a more detailed review of the effects of debris (physical quality) on risks to people. This includes the direct effects of impacts of debris on people and indirect affects (e.g. damage to buildings and subsequent collapse). This investigation will provide a refinement of the debris factor developed on Phase 1, and will also support flood risk awareness messages in some circumstances.

A significant concern is also the impact of polluted flood water on human health, from both biological and chemical pollution. The emphasis of this project is on ‘physical’ risk but previous research will be reviewed to establish whether a water quality factor could at some stage be incorporated into the overall risk to people methodology. This will take account of previous research into health effects from flooding.

5 Behaviour of people during floods

An issue of particular concern is the significant loss of life that occurs as a result of the behaviour of individuals during floods. Whilst this is difficult to predict and quantify, it is nevertheless a significant factor Better knowledge of behaviour in the event of flooding, and the links between behaviour and risk, could help to target risk awareness messages. The purpose of this approach will be to investigate incidents of injury/loss of life due to the behaviour of people during floods, and propose a method for taking this into account in the overall methodology. Whether or not this is integrated into the overall risk methodology will be decided by the project stakeholders.

The method may be based on statistics from historic floods, or a more general assessment of the likelihood of injury/loss of life due to the behaviour of individuals. The types of behaviour that lead to injury/loss of life include panic and curiosity. An example is attempting to drive through flood waters, which can lead to cars being washed downstream.

6 People Vulnerability Index

A 'People Vulnerability' Index or parameter will be developed of a similar type to the SFVI used in the Modelling and Decision Support Framework for CFMPs but with different variables and scoring. The exact parameters and relationships may include such factors as children, ethnic minorities and other health issues in addition to elderly and pre-existing health problems.

7 Further testing and refinement of the methodology

A complete methodology for assessing flood risks to people was developed during Phase 1. It includes a range of assumptions based on experience that allowed the method to be demonstrated. The purpose of this approach is to:

- Review the assumptions;
- Refine the methodology; and
- Test the methodology using a wider range of case studies to ensure that the results are reasonably reliable in a range of different situations.

The aspects of the methodology to be refined include:

- Definition of hazard rating, to be developed in Approach 1 above;
- Definition of area vulnerability, possibly including the effectiveness of flood warning assessed in Approach 2 above;
- Definition of people vulnerability and behaviour of people during floods, assessed in Approaches 4 and 5 above, and the effects of regular flooding on risks to people;
- The relationship between injuries and fatalities.

The primary methods for this approach will be literature review and analysis. The methodology will be refined and tested in some detail using a wider range of case studies. In some cases it may be found that there is no justification for changing part of the methodology. In such cases, justification of why the particular assumptions were adopted will be provided.

8 Uncertainty in the results and confidence limits

The 'Risk, Performance and Uncertainty Review (FD2302/TR1) recommended a classification for uncertainty, and that will be followed here. The results produced by the risk assessment method could be uncertain, partly because of assumptions made in the method, but mainly because of the lack of reliable data on historic events that caused injury/death. This approach involves the development of a procedure for estimating uncertainty and stating the degree of confidence for predictions given by the method. Note that in some cases these may be reported in terms of 'categories' of confidence, rather than a as mathematical confidence interval. This type of approach is more applicable to large uncertainties associated with lack if knowledge, or where there is not enough data to make a rigorous statistical analysis. The aim will be to provide realistic reporting of the overall uncertainly in the results, to help to target future refinement and to be open and honest about the uncertainties.

9 Guidance document on flood risks to people

The purpose of this approach is to disseminate the findings of the project to all those concerned with flood risks to people. A guidance document will be produced on the causes of flood risks to people and how these can be assessed and managed. Guidance will also be provided on mitigation measures where appropriate. Beneficiaries of the guidance will include Agency flood warning, flood defence, strategic planning and development control staff, emergency planners, emergency services, local authorities and those affected by flooding.

10 Information for ongoing research

A summary document will be prepared containing information related to risk of death and serious physical injuries to people by flooding, for on-going research projects. The information will include advice on how the ongoing research projects might benefit from the Risks to People research. Relevant ongoing and planned projects include the MDSF, RASP, PAMS and Flood Foresight.

11 Basis for flood hazard and vulnerability mapping

A summary document will be prepared containing recommendations for a basis for the Agency's Flood Hazard and Vulnerability Maps. This will include recommendations for the mapping method and dealing with issues such as scale, accuracy and links with other mapping and data.

The document will include a development path for the Agency's Flood Hazard and Vulnerability Maps including the steps needed for implementation (see Priority 4 items above).

Milestone	Target date	Title
1	30/12/2003	Inception report, including outcome of consultations
2	30/04/2004	Interim Report 1, including results of collecting flood hazard and flood hazard prevention information (regulations and the flood warning). The report will also include the results of the evaluation of flood warning effectiveness.
3	31/07/2004	Interim Report 2, including results of the impact of the water quality Scoping Study (physical, chemical and biological pollution from major installations) and the social studies including information about acceptable and allowable risks to people.
4	31/12/2004	Technical Report on all studies including the contents of the Interim Reports and provide a base for Agency's Flood Hazard and Vulnerability Maps
5	31/01/2005	Draft Guidance Document, summary document for ongoing research and summary document for mapping.
6	28/02/2005	Final Guidance Document, summary document for ongoing research and summary document for mapping.

Staff effort

David Ramsbottom of HR Wallingford is a specialist in flood management with a broad knowledge of flood management measures, flood warning and emergency planning. He has over 25 years experience in water engineering and management and most of his work has been on flood management since joining HR Wallingford in 1988. He was responsible for the development of the Modelling and Decision Support Framework for Catchment Flood Management Plans, which includes mapping of flood risk areas and manipulation of national data sets to calculate economic damages and social impacts of flooding. He has recently provided guidance to Defra on floodplain management and flood emergency planning, which includes the assessment of flood hazard. He was the project manager for Phase 1 of the Flood Risks to People project.

Susan Tapsell of the Flood Hazard Research Centre has 12 years experience of designing and managing quantitative and qualitative research projects, with particular reference to the public perception of flood risk, flood defence schemes, river restoration, river environments, and the intangible effects of flooding. Most recent research on the health and social effects of flooding in the north-east of England (particularly relating to vulnerable groups within communities), and children's perception and use of river environments. Experienced in research with floodplain residents and flood victims and in conducting in-depth interviews with key informants within government departments, local authorities, and the voluntary sector.

Professor Edmund Penning-Rowsell of the Flood Hazard Research Centre has more than 25 years experience of analysing floods and investment in flood alleviation, river management, water planning, and landscape assessment. Research and consultancy experience has been gained in Hong Kong, Australia, Argentina, China, as well as in numerous European Union countries (principally France, Germany, Portugal and The Netherlands). This research work has including development of the standard UK techniques for economic assessment of flood damages and a range of studies on the physical and social impacts of flooding on people.

Dr Peter Floyd, a Director of RPA, has more than 20 years experience in applying risk assessment techniques to a wide range of projects around the world, including numerous studies of flood hazards/risks. Dr Floyd is currently directing the major DEFRA/Environment Agency project on the 'intangible' impacts of flooding (FD2005). He was involved with looking at extreme floods for the Environment Agency which informed the development of PPG25 as well as being involved with PAG4 (*Approaches to Risk Assessment*) as both author and Steering Group member. He has also been actively involved in the preparation of a number of flood and coastal defence strategies and brings experience of clear reporting and concise writing. He developed the Phase 1 methodology in the Flood Risks to People project.

Carolyn George is a Consultant with RPA. Ms George has worked on a number of projects involving extensive data collection, review, consultation and analysis. Recent projects include: data collation and analysis for the UKCIP project on handling risk and uncertainty associated with future change. She is actively involved in the ongoing major project on the intangible impacts of flooding and provided RPA's contribution on climate change to the major *Futurecoast* project.

Communication of results and Technology transfer

Results will be presented to stakeholders in a range of formats, depending on the outcome of the consultations. It is likely that summary results for each part of the research will be issued as the work proceeds, in addition to the final guidance document. It is proposed to submit summary articles to journals read by stakeholder groups, and present results at relevant conferences and meetings, particularly the Defra Conference and meetings of the Environment Agency flood warning team, regulation team and emergency planners.

Involvement of stakeholders throughout the project. It is expected that stakeholders will advise on technology transfer as the work proceeds and the value of the outputs becomes apparent.

Benefits

The project has a number of potential applications, including:

- Primary purpose: methodology for assessing and managing flood risks to people, for use by a range of stakeholders including Defra and Agency staff, emergency planners and the emergency services
- Identification of hotspots where risks to people are high
- Improved guidance under PPG25
- Better targeting of flood warnings and regulation
- Better emergency planning
- Better advice to people in flood risk areas
- Basis for Agency's Flood Hazard and Vulnerability Maps
- Information for on-going research and their improvements (e.g. MDSF, RASP, PAMS and Flood Foresight).

Appendix C

Relevant Incidents from MHIDAS Data-base

Table C.1: Relevant Incidents from MHIDAS Data-base for UK

Mm/Yr	County	Town	Facility	Material	Ninj	Nfat	Outline
06/82	Derbyshire	Staveley	Chemical Factory	Sulphur Trioxide	?	0	Drums of waste sulphur trioxide and oleum, which had been buried in a pit, caused explosion during heavy rainfall as result of chemical reaction. Drums were hurled 300m and cloud of acidic mist drifted over the town causing irritation.
01/90	Dyfed	Milford Haven	Railtanker	Oil	0	0	Oil tanker train derailed, 1 of 10 wagons and loco overturning. Firemen maintained foam blanket at scene. Oil spilled onto gas main adjacent to track. Accident due to flooding. Road closed and traffic diverted as a precaution.
07/91	Kent	Gillingham	Storage Tank	Chemicals	0	0	Tank overturned, hit JCB and split spilling 3000gall chemicals, probably due to heavy storm softening ground. Spill contained to sewage system.
07/99	Essex	Barking	Factory	Xylenes	0	0	Chemicals leaking from a nearby factory were washed into the cellar of a pub when it was flooded with rainwater. The pub has had to close indefinitely.
07/99	Humberside	Grimsby	Refinery	Oil	0	0	Oil leaked from a refinery during a very bad storm. A storm water pump was not switched on soon enough to cope with the deluge of rain. Water built up in the refinery drains, causing the system to overflow and oil to leak into the nearby saltmarsh.
02/00	Staffs	Stafford	Foundry	Sodium	0	0	A leak in factory roof allowed rainwater to come in contact with stored sodium. The initial fire had gone out by the time fire crews arrived although the building was smoke-logged and the sodium boxes still smouldering. No-one working in foundry.

Note: In this and subsequent tables, Ninj and Nfat are the numbers of reported injuries and fatalities respectively.

Table C.2: Relevant Incidents from MHIDAS Data-base for USA

Mm/Yr	Country	State/Area	Facility	Material	Ninj	Nfat	Outline
Pre03/78	USA	Alabama	Pipeline	Natural Gas	0	1	Natural gas leaking from cast iron main migrated into house from recently backfilled sewer drain and was ignited by cigarette lighter. Resulting explosion and fire destroyed house and fatally injured 1 occupant. Earth settlement and heavy rain caused failure.
??/78	USA	New York	Waste	Waste Chemicals	0	0	99 houses and primary school built adjacent to "Love Canal" which for 30 years had been used for chemical waste disposal. Heavy snowfall brought chemicals to surface, depositing them in cellars.236 families evacuated and site quarantined
11/79	USA	Florida	Railtanker	Propane	0	0	29 cars of 109 car train derailed in swampy area following erosion of roadbed by heavy rain. 6 cars of LPG caught fire causing evacuation of 2.5mile radius. Explosives experts blew up remaining cars after 3 days to prevent explosions and speed burning.
01/80	USA	Washington	Railtanker	Ammonia	2	2	Mud slide caused derailment of 19 railcars (Burlington Northern) one person killed as a result of impact, another was severely injured with burnt lungs due to inhaled ammonia gas
07/80	USA	Illinois	Waste	Waste Oil	0	0	Approximately 12000gall waste oil contaminated with polychlorinated biphenyls and dicyclopentadiene and heavy metals spilled after heavy rain caused storage ponds to overflow. Public concern since over 100000kg had been lost on this site in 3 years.
10/81	USA	Texas	Fuel Depot	Petrol/ Diesel	0	0	3*30000gall tanks (2 gasoline and 1 diesel fuel) floated, broke their piping and rolled over during heavy flooding at truckstop. 10000gall spilled. After flood receded, firefighters used foam to seal remaining vapours and vacuum trucks to pick-up residue.
06/84	USA	Iowa	Barge	Fuel Oil	0	0	Barge “Bettendore" hit concealed (by flood stage of river Mississippi) piling when entering lock. Gash 10'*6'. Crew attempted to pump oil from compartment no.2 (of 10) but almost all was lost. Oil dissipated immediately in currents. No clean-up needed.
06/86	USA	Texas	Railtanker	Butadiene	5	0	Flood-weakened bridge collapsed as Missouri pacific co. Train was crossing. Explosion in tanker of butadiene caused fire involving cars of butadiene/formaldehyde/ethylene glycol.2mile radius sealed off. Burning trucks left to burn out.
03/87	USA	Florida	Waste	Waste Chemicals	0	0	Storage tank overfilled when high-level alarm failed during heavy rains.100000gall wastewater containing cadmium/chromium/methylene chloride and phenol overflowed.65000gall flowed by natural drainage into Tampa bay.
07/88	USA	Texas	Oil Depot	Gasoline	0	0	Heavy rains accumulated on the floating roof of 80,000bbl storage tank and pushed

Table C.2: Relevant Incidents from MHIDAS Data-base for USA

Mm/Yr	Country	State/Area	Facility	Material	Ninj	Nfat	Outline
							the roof down into the gasoline. As foam was being applied gasoline ignited by unknown source. Some fuel was saved by transferring it during fire fighting.
01/91	USA	New Orleans	Pipeline	Oil	0	0	Floodwater on Mississippi caused 15 barges to break free from moorings and sever 500 mm diameter pipeline at dock. 19000 litres spilled
06/91	USA	Texas	Pipeline	Crude Oil	0	0	Heavy rain caused 10 inch pipeline to collapse spilling 34000galls crude oil to river. Storm washed out pipeline support causing it to sag and break. Weather allowed spill to travel 75 miles from source. Oil finally contained by 6 km of boom.
08/92	USA	New York	Petrol Station	Petrol/Diese l	0	0	Service station under renovation flooded due to heavy rains. Gasoline and diesel fuel escaped via a constant stream of rainwater. Storm drains were diked and water flow dammed. Fire department were at site for just under three hours.
01/93	USA	Arizona	Pipeline	Natural Gas	0	0	Pipeline failure caused by collapse of river dam. Bypass built around damaged section
08/93	USA	Missouri	Storage Depot	Propane	0	0	51 tanks, each containing 30,000galls propane, floated from their supports as river flooded over earthen levee. Leaking vapours at pipe connections ignited with flash fires. Tanks were strapped down and attached to concrete base.
10/94	USA	Texas	Pipeline	Gasoline	<70	0	40" gasoline pipeline ruptured in floodwaters. Leaked and ignited. 36" fuel oil pipeline ruptured shortly afterwards. Believed 1st damage caused by large object striking pipelines or by loose moorings allowing pipes to snap. Floods shutdown ethylene site.
12/94	USA	Texas	Pipeline	Natural Gas	0	0	Natural gas pipeline ruptured during severe flooding.
06/96	USA	Michigan	Chemical Plant	Hcl	0	0	Power outage when torrential rains caused flooding that resulted in short circuit at plant manufacturing polycrystalline silicon for computer chips led to emergency venting of hydrogen chloride gas to relieve dangerous build-up of pressure.
04/01	USA	Rhode Island	Old Oil Tank	Oil	0	0	Estimated 1000 us gallons of industrial oil spilled from an abandoned underground storage tank. It is thought the tank filled with rain and groundwater and began to leak. Most was contained on site or soaked into the soil. Some entered the local river.
06/01	USA	Louisiana	Oil Storage	Gasoline	0	0	Heavy rains caused layer of gasoline to build up on top of a floating roof tank. Product was being drained when lightning struck causing major fire. Draining continued as specialist fire fighting teams were mobilised. Fire extinguished with foam.
07/01	USA	W Virginia	Domestic Fuel Storage	Fuel Oil and Propane	0	0	Record flooding left hundreds of household fuel tanks damaged. Some 1,500 to 2,500 homes were destroyed and hazmat crews have been brought in to deal with the fuel tanks.

Table C.3: Relevant Incidents from MHIDAS Data-base for Rest of World

Mm/Yr	Country	State/Area	Facility	Material	Ninj	Nfat	Outline
11/67	Portugal	Lisboa	Warehouse	Phosphorous	12	0	Ammunition dump exploded on northern outskirts of city when floodwaters reached phosphorus.12 people slightly injured in blast.3000 evacuated from area after blast.
11/67	Kuwait		Warehouse	Calcium Carbide	0	0	Fire in vehicle yard and stores of Hassan Al Kaz burned all day destroying several "Holden" cars, "Scandia-Vabis" lorries and stocks of tyres, vehicle spares and motor oil. Cause thought to be rainwater reaction with calcium carbide in drums.
07/79	India	Bombay	Docks	Chemicals	>1	0	Severe floods. Rainwater onto shed no 14 Victoria dock caused some drums of chemicals to catch fire. firemen were being overcome by fumes so broke shed roof for ventilation, this caused more damage to other goods
08/83	France	Bayonne	Warehouse	Cyanide	4	0	Heavy rain led to severe flooding which washed 100*50kg drums of cyanide from warehouse in Bilbao out sea.28 drums beached in France causing respiratory problems when toxic fumes inhaled.
08/84	Canada	??	Chemical Plant	Acetylene	0	0	Shawinigans Chemicals Co. An explosion followed by a fire occurred when heavy rain penetrated a warehouse causing release of acetylene from calcium carbide.
01/87	Australia	Melbourne	Chemical Plant?	Acids	0	0	Rainwater leaked into tank containing nitric/sulphuric acids. Water reacted with acids and ruptured tank. Large yellow toxic cloud released which spread across Melbourne and did not disperse until next day.
11/88	St Lucia	Castries	Chemical Plant	Esters	0	0	Small craft inlet adjacent to bitumen plant was affected by higher esters washed into creek after heavy rain. Several small craft affected.
08/91	CIS	Moldavia	Refinery	Oil Products	0	0	Floods caused by heavy rain caused more than 200te oil products to be spilled to river. Oil spilled from refinery.
08/91	CIS	Tuapse	Pipelines	Oil Products	0	0	Tornado smashed gas pipelines and polluted beaches as hundreds of tons of oil products spilled into river and sea as a result of flooding after storm.
10/93	France	Lyon	Railtanker	Acetone	0	0	Part of train carrying acetone derailed after rainstorms caused mudslides and cut off roads and railways. No pollution.
03/94	Peru	Amazon	Pipeline	Crude Oil	0	0	Turbulent waters eroded earth around 24" pipeline. Over 3000t crude leaked from ruptured pipe to Amazon river tributary. Area is of great value because of variety and richness of animal species there.
11/94	Egypt	Dronka	Railcar and Storage	Fuel Oil	?	>58 0	Floods caused rail track to subside and two tank wagons overturned. Fuel ignited and spread to other tanks. Lightning struck complex of 8 tanks with 15000te aircraft fuel at military site in flooded town. Flaming fuel spread through town killing >580.

Table C.3: Relevant Incidents from MHIDAS Data-base for Rest of World

Mm/Yr	Country	State/Area	Facility	Material	Ninj	Nfat	Outline
08/95	Japan	Nagaoka	Pipeline	LNG	0	0	350mm diameter 23.5km pipeline ruptured by landslide caused by heavy rains in area. No casualties and processing plants not damaged. Four hour fire resulted from break.
12/97	Sri Lanka	Colombo	Pipeline	Crude Oil	0	0	Crude oil leaked from an abandoned pipeline following heavy rains. It had been thought that the pipeline had previously been sealed.
05/99	Peru	Amazon	Pipeline	Crude Oil	0	0	Heavy rains caused a landslide which damaged a major oil pipeline. Between 125000 and 8000bbls were spilt. Some possibly reached the Maranon river. Heavy rains were hampering repairs.
01/00	Bolivia	Oruro	Pipeline	Crude Oil	0	0	A flash flood weakened supports and caused a small fracture in a main export pipeline. Estimated 714 tonnes of oil was lost into Desaguardero River but actual quantity unknown. Cleanup operations underway. Oil spilled for 18 hours before pumping ceased.
05/00	Ukraine	Cherkassy	Railcars	Ammonia	0	0	Six tank cars of freight train derailed after heavy rains undermined track. Around 100 tonnes of ammonia solution spilt to ground. Nearby residents evacuated, no injuries reported.
11/00	Mexico	Veracruz	Pipeline	Crude Oil	0	0	A fractured 12-inch pipeline leaked 155 cubic metres to two rivers which feed into a system of lagoons. Spill was contained after contaminating a six mile (10 km) stretch of water. Local fishermen unable to work due to spill.
05/01	Russia	Siberia	??	Fuel Oil	0	0	Fuel leaked from reservoirs damaged by flooding, spilling into a swollen river and mixing with cracked ice. The scope of the spill had not yet been determined. The flood waters had also destroyed 10,000 homes and killed 6 people.
06/01	Ecuador	Papallacta	Pipeline	Crude Oil	0	0	Landslide, caused by torrential rain, damaged 60m crude oil pipeline losing 10,000bbls of oil. Pumping expected to be suspended for 4 to 5 days. A section of pipeline carrying domestic cooking gas was also ruptured, losing up to 1000bbl, which ignited.
07/01	Canada	British Columbia	Railcars	Diesel	0	0	Two locomotives plunged over a 7 metre embankment after flood waters washed out the rail bed. Two diesel tanker cars ruptured and spilled thousands of litres onto wetlands above the Fraser river. The river was not at risk of pollution.
07/02	Romania	Manesti	Pipeline	Crude Oil	0	0	Pipeline damaged due to swollen Prahova river and leaked 9m3 of oil. Dams placed along river but ineffective due to high water flow.

Table C.3: Relevant Incidents from MHIDAS Data-base for Rest of World

Mm/Yr	Country	State/Area	Facility	Material	Ninj	Nfat	Outline
08/02	Romania	Bucharest	Pipeline	Crude Oil	0	0	High floodwaters in the Ploiesti oil field broke a pipe at an oil well in the early hours. Crude oil poured into the river Prahova causing pollution of the water. Six floating dams were deployed to attempt to limit the effect of the release (same as previous incident??)
08/02	Czech Republic	Prague	??	Chlorine	0	0	Tank was damaged by flooding. This tank was subsequently pumped out and chlorine gas was released. A cloud of gas was visible around the chemical plant. The gas dispersed rapidly.
08/02	Czech Republic	Neratovice	??	Chlorine	0	0	Factory was hit by flood water and this caused release of initially 400kg of chlorine, and then further release of 500kg. Large releases of mercury and dioxins were also reported. No human causalities however there was damage to trees and crops in area (same as previous??)
11/02	Morocco	Mohammedi a	Refinery	Oil	0	2	Hydrocarbon residues / waste oil contacted hot refinery equipment, as result of severe flooding in area, causing fire. Second blaze, involving fire / explosion in storage tanks, reported. 2 charred bodies recovered during rescue operations.

APPENDIX D

The COMAH *(Control of Major Accident Hazard) Regulations 1999* implement *EC Directive 96/82/EC* (known as the *Seveso II Directive*). They cover sites in the UK that use or store dangerous substances such as oils, gases, chemicals or explosives. The Environment Agency together with the Health and Safety Executive (HSE) is the Competent Authority to implement these regulations for England and Wales. The aim of the COMAH regulations is to prevent major accidents occurring in these sites (Environment Agency). These regulations apply to over 1100 sites in England, Wales and Scotland. Approximately 750 are 'lower tier' sites and the remaining 350, with larger inventories of dangerous substances, are classified as 'top tier' (HSE, 2003). Sites are classified according to the quantity and toxicity of the substances stored on site.

In Schedule 1 of the COMAH Regulations (http://www.hmso.gov.uk/si/si1999/19990743.htm) threshold quantities are specified for named substances and categories of substances and preparations. COMAH sites are classified as top tier or lower tier depending on the threshold exceeded. The tables in Part 2 and 3 of the Schedule show a list of dangerous substances and the qualifying quantities. Column 2 shows the threshold limit for Lower Tier COMAH sites and Column 3 the threshold for Top Tier sites (See Tables 2 & 3).

Examples of where a risk to life from flooding can be associated with the storage of such materials have been provided in the first Interim Report. As outlined, the impact of contaminated floodwaters can be either direct (Spolana (Milmo, 2002)) or indirect (Staveley Chemicals Limited, (HSE, 1982)). Floodwaters not only can transport pollution off site, to cause harm there, but may also cause chemical reaction or explosions when in contact with hazardous substances. On the other hand, floodwaters have an important dilution effect that reduces the contamination.

Floods may also damage infrastructures such as rail tracks, roofs or pipelines thus leading to explosions, fires and/or toxic releases.

The location of storage, the way dangerous chemicals are stored and the adequacy of staff training are clearly critical to the impact of a flood upon a potentially hazardous installation.

It is clear that flooding can initiate or exacerbate major accidents. Increased floodplain development, together with the growth of industrial activities in those areas, could contribute to a number of catastrophes.

Factors influencing the hazard rating for an installation include:

- Location of the installation and in particular location on a floodplain or proximity to a floodplain.
- The history of flooding in the area (flood frequency).
- The characteristics of flooding within the area (flash flooding or slow rise)
- Proximity to the area of high population density
- Proximity to vulnerable groundwater or nitrogen sensitive zones

- Proximity to a drinking water abstraction point
- Proximity of agricultural land
- Category of land use present
- Substances being stored
- How substances are being stored
- Designated COMAH, IPC/PPC site

A significant number of properties are located within the indicative[23] floodplains of England and Wales (Figure 1 and Table 1). It would therefore be expected that there are facilities within these indicative floodplains which represent a risk to life from flooding. Figure 1 provides an indication of three types of installations: landfills, IPC and COMAH sites, by region. These represent both tidal and fluvial floodplain locations.

[23] For fluvial flooding, the indicative floodplain extends to the 1 in 100 year contour and for tidal flooding, the indicative floodplain extends to the 1 in 200 year contour.

Figure 1: Distribution of Landfills, IPC and COMAH Sites by Region

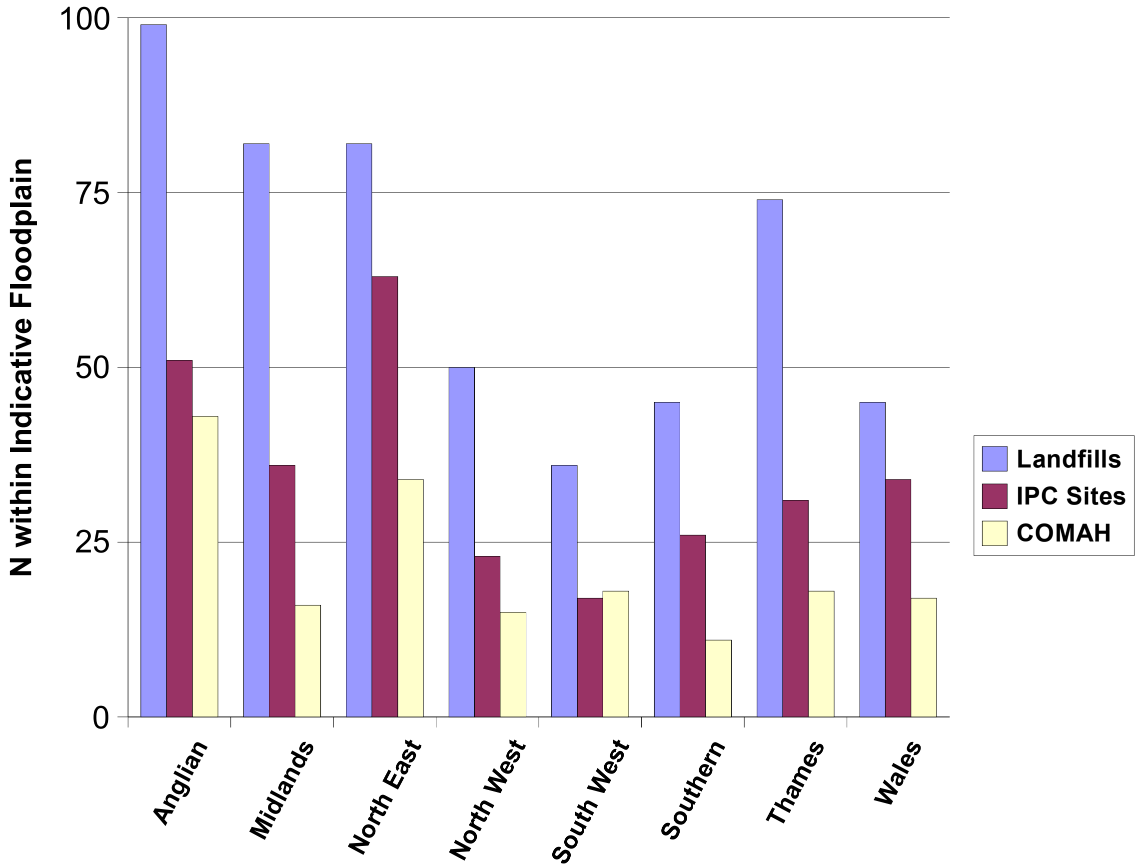

Table 1: Numbers of Facilities within the Indicative Floodplains (IFP) of England and Wales

Type of Facility	Number in IFP	%Tidal	Total (E&W)	% in IFP
Landfill	513	32%	1690	30%
IPC Site	281	64%	1320	21%
COMAH Site	172	74%	1100	16%

Sources: The national totals are RPA estimates based on data from the Agency website (landfills), Friends of the Earth (IPC sites for 1999/2000) and HSE website (COMAH).

It is clear that a disproportionately large number of potentially polluting facilities (particularly landfills) are located within the indicative floodplain.
In terms of providing a hazard rating for such sites one would need to consider the combination of factors listed above on a site by site basis.

One factor that may increase the flood risks to people associated with such sites is the 'domino effect'. The 1999 COMAH Regulations require the competent authority (CA) to:

'*designate groups of establishments where the likelihood or consequences of a major accident may be increased because of the location and proximity of the establishments in the group and the dangerous substances present there - the so called domino effect.*'

A contour known as the ‘Consultation Distance’ is assigned to each COMAH site for land use planning purposes. Where the ‘consultation distance’ of a site overlaps with the boundary of another COMAH site, it will be used as the basis to group COMAH sites. Information is (should be) exchanged between operators of ‘domino groups’ including details of the type of activities and substances stored and information on the means by which they could trigger major events at other establishments.

Operators take this information into account in both their on-site and off-site emergency plans by, for instance, including drawings showing the ‘domino circles’ where risks have been identified to ensure that action is taken to mitigate the potential risks.

In Regulation 6 Notifications administrative consultation distances are given for:

- Sites with flammable/explosive risks 500m
- Sites with toxic risks 1000m

It could be argued that the potential risk associated to the flooding of a COMAH site is much greater if there are other hazardous sites in the same area. For instance, contaminated water from a flooded COMAH site could enter an abstraction system at another COMAH site which could trigger a major accident.

One could argue that where hazardous substances are stored at a COMAH site the risk to life from flooding is small as questions relating to the location of the site and its proximity to people and potentially sensitive land uses have already been asked and used to assess the amount and type of hazardous materials that can be stored on site. Staff training is a pre requisite for the establishment of these sites as are the compilation of Major Accident Prevention Plans (MAPPs) and site safety reports. The hazard is greater at sites which are less rigorously regulated e.g. where small quantities of hazardous materials are stored. To quantify the risk to life from flooding at these sites one would need to collate data on location and location characteristics and generate domino circles around each storage point.

Table 2: Dangerous substances and qualifying quantities (Adapted from Schedule 1of the COMAH Regulations)

Dangerous substances	*Quantity in tonnes*	
	Top tier	*Lower tier*
Ammonium nitrate (as described in Note 1 of this Part)	350	2,500
Ammonium nitrate (as described in Note 2 of this Part)	1,250	5,000
Arsenic pentoxide, arsenic (V) acid and/or salts	1	2
Arsenic trioxide, arsenious (III) acid and/or salts	0.1	0.1
Bromine	20	100
Chlorine	10	25
Nickel compounds in inhalable powder form (nickel monoxide, nickel dioxide, nickel sulphide, trinickel disulphide, dinickel trioxide)	1	1
Ethyleneimine	10	20
Fluorine	10	20
Formaldehyde (concentration =>90%)	5	50
Hydrogen	5	50
Hydrogen chloride (liquefied gas)	25	250
Lead alkyls	5	50
Liquefied extremely flammable gases (including LPG) and natural gas (whether liquefied or not)	50	200
Acetylene	5	50
Ethylene oxide	5	50
Propylene oxide	5	50
Methanol	500	5,000
4, 4-Methylenebis (2-chloraniline) and/or salts, in powder form	0.01	0.01
Methylisocyanate	0.15	0.15
Oxygen	200	2,000
Toluene diisocyanate	10	100
Carbonyl dichloride (phosgene)	0.3	0.75
Arsenic trihydride (arsine)	0.2	1
Phosphorus trihydride (phosphine)	0.2	1
Sulphur dichloride	1	1
Sulphur trioxide	15	75
Polychlorodibenzofurans and polychlorodibenzodioxins (including TCDD), calculated in TCDD equivalent	0.001	0.001
The following CARCINOGENS:		
4-Aminobiphenyl and/or its salts, Benzidine and/or salts, Bis(chloromethyl) ether, Chloromethyl methyl ether, Dimethylcarbamoyl chloride, Dimethylnitrosomine, Hexamethylphosphoric triamide, 2-Naphthylamine and/or salts, 1,3 Propanesultone and 4-nitrodiphenyl	0.001	0.001
Automotive petrol and other petroleum spirits	5,000	50,000

Table 3: Categories of Substances and Preparations not specifically named in Table 1 (Adapted from Schedule 1of the COMAH Regulations)

Categories of dangerous substances	*Quantity in tonnes*	
	Lower tier	*Top tier*
1. VERY TOXIC	5	20
2. TOXIC	50	200
3. OXIDISING	50	200
4. EXPLOSIVE (a substance or preparation which creates the risk of an explosion by shock, friction, fire or other sources of ignition)	50	200
5. EXPLOSIVE (a pyrotechnic substance is a substance (or mixture of substances) designed to produce heat, light, sound, gas or smoke or a combination of such effects through non-detonating self-sustained exothermic chemical reactions, or an explosive or pyrotechnic substance or preparation contained in objects)	10	50
6. FLAMMABLE	5,000	50,000
7a. HIGHLY FLAMMABLE	50	200
7b. HIGHLY FLAMMABLE liquids	5,000	50,000
8. EXTREMELY FLAMMABLE	10	50
9. DANGEROUS FOR THE ENVIRONMENT in combination with risk phrases:		
"Very toxic to aquatic organisms"	200	500
"Toxic to aquatic organisms"; and	500	2,000
"May cause long-term adverse effects in the aquatic environment"		
10. ANY CLASSIFICATION not covered by those given above in combination with risk phrases:	100	500
"Reacts violently with water"		
"in contact with water, liberates toxic gas"	50	200

References

Environment Agency, Control of Major Accident Hazard Regulations 1999 (COMAH) http://www.environment-agency.gov.uk/business/444217/444663/comah/?version=1&lang=_e)

HSE (2002) COMAH Safety Report Assessment Manual. Domino Effects. http://www.hse.gov.uk/hid/land/comah2/pt1ch7.htm#APPENDIX%201 (accessed 1/10/04)

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APPENDIX E

The Social Flood Vulnerability Index

The Index and its constituents

The SFVI is a composite additive index based on three social characteristics and four financial deprivation indicators. The rationale for the selection of these variables is given in Table 3, and Figure 2 maps these and other variables against the six case studies that we have undertaken over several years to quantify the 'intangible' impacts of flood events. The linkages shown in Figure 2 are based on our best judgement, supported by results from the hundreds of interviews in those studies, of the relative effect of the different variables in determining household vulnerability in the types of floods experienced in those localities. It shows that the age and financial status of the affected populations are the most commonly important variables, followed by the prior health status of the population. We have chosen to use the incidence of lone parents as a measure of family structure, because our research points to this causing extremes of vulnerability, although the presence or absence of young children (to which the incidence of lone parents is very closely correlated) had perhaps an equal case for inclusion.

To identify the financially deprived, the Townsend Index (Townsend 1984) was used because, unlike other deprivation indices, it focuses on deprivation outcomes (such as unemployment), rather than targeting predefined social groups. This enabled us to identify our own social classification. This is important because financial deprivation is only one of several factors that contribute towards vulnerability to flood impacts and it is our intention to target only those social groups which previous research has shown to be particularly badly affected.

The Townsend indicators are:

1. Unemployment – unemployed residents aged 16 and over (S090019 + S090043) as a percentage of all economically active residents aged over 16 (S090013 + S090037)[24].

2. Overcrowding – households with more than one person per room (S230003 + S230004) as a percentage of all households (S230001).

3. Non-car ownership – households with no car (S210003) as a percentage of all households (S210002).

4. Non-home ownership – households not owning their own home ((S200001 + S200009) – (S200002 + S200003)) as a percentage of all households (S200001 + S200009).

In order to prevent any undue bias in the SFVI towards financial deprivation, the four Townsend indicators were summed and multiplied by 0.25 before being added to the other variables. Those other variables and the social groups that they highlight are:

1. The long-term sick – residents suffering from limiting long-term illness (S120001) as a percentage of all residents (S010064).

2. Single parents – lone parents (S400001) as a proportion of all residents (S010064).

3. The elderly – residents aged 75 and over (S020127 + S020134 + S020141 + S020148) as a percentage of all residents (S010064).

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[24] These codes refer to the tables provided by MIMAS. Hence S090019 refers to census Small Area Statistics, table 09, variable 19

Table 3: Our rationales for the selection of variables for the Social Flood Vulnerability index (based on qualitative focus group research)

Variables	Rationale
Elderly (Over 75 years of age)	The age of 75 was chosen because epidemiological research has shown that after this age there is a sharp increase in the incidence and severity of arthritis [and other conditions] and this illness is sensitive to the damp, cold environmental conditions that would follow a flood event.
Lone parents	Previous FHRC research has shown that lone parents (of either sex) are badly affected by floods because they tend to have less income and must cope single-handedly with both children and the flood impacts, with all the stress and trauma that this can bring.
Pre-existing health problems	Research by FHRC has shown that post-flood morbidity (and mortality) is significantly higher when the flood victims suffer from pre-existing health problems.
Financial deprivation	The financially deprived are less likely to have home contents insurance and would therefore have more difficulty (and take a longer time period) in replacing households items damaged by a flood event.

Data Processing

The crude percentages were transformed by the method that produced the minimum skewness and kurtosis within their distributions. The selected transformation methods are shown in Table 4. Following transformation, the data were standardised as Z-scores and then summed (as stated above, the Townsend indicators were summed separately and then multiplied by 0.25 prior to their inclusion in the index).

Table 4: Transformation methods used in the compilation of the SFVI

Indicator	Transformation method
Lone parents	Log natural (x + 1)
Aged 75+	Log natural (x + 1)
Long term sick	Square root
Non home owners	Square root
Unemployed	Log natural (x + 1)
Non car owners	Square root
Overcrowding	Log natural (x + 1)

The completed SFVI has a minimum value of -10.4, a maximum value of 9.07, a mean of 0.06 and a standard deviation of 2.56. Given the relatively exploratory nature of this work the SFVI was then categorised into a limited number of bands (5), where category 1 represents low vulnerability, category 3 average vulnerability and category 5 high vulnerability, etc. Also, out of 113,465 EDs in England and Wales there are 4982 missing values. This is due to either null values in the indicators or, in some cases, data for the ED is 'suppressed'. Data for a ward or ED is suppressed when its population is considered to be so low that individual households or persons could be identified from the census data that is released.

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