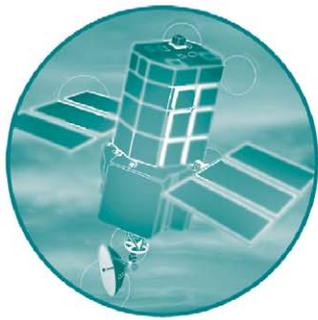


# DEFRA/Environment Agency Flood and Coastal Defence R&D Programme



## Flood Risks to People Phase 1

R&D Technical Report  
FD2317/TR

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

**Flood Risks to People**

**Phase 1**

R&D Technical Report FD2317/TR

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## **Dissemination Status**

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This technical report contains the results of Phase 1 of a study to identify flood risks to people which occur as a direct result of a flood or within one week of the event. The study is aimed primarily at staff of the Environment Agency, emergency planners, the emergency services and others involved in flood emergency planning and responding to floods.

## **Keywords**

Flooding, Risk, Loss of Life, Hazard.

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R&D OUTPUTS: FLOOD RISKS TO PEOPLE: PHASE 1 FD2317/TR

## EXECUTIVE SUMMARY

The overall objective of the project is to develop a methodology for assessing and mapping the risk of death or serious harm to people caused by flooding.

The project is divided into two phases. Phase 1 is concerned with evaluating existing knowledge and developing the overall framework for the project. Phase 1 also identifies specific research needs to achieve the overall objective, and these will be carried out in Phase 2. This document is the Final Report for Phase 1.

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
- c) deaths/physical injuries associated with the flood event (but occurring in the immediate aftermath).

It is recognised that whilst categories (a) and (b) will be directly related to characteristics of the flood and the affected population, there may be a range of other relatively random factors that contribute to category (c).

The main factors that cause death/injury to people during floods include flow velocity, flow depth, and the degree to which people are exposed to the flood. The exposure potential is related to such factors as 'suddenness' of flooding (and amount of flood warning), size of floodplain, location on floodplain, type of accommodation, etc. In addition, risks to people are affected by social factors including vulnerability and behaviour.

Some research has already been carried out relating the risk of death to different causative factors. They have been derived by a range of different methods and apply to different conditions, for example dambreak, coastal flooding, etc.

A methodology is described for estimating the likely annual number of deaths/injuries. It is based on defining zones of different flood hazard and, for each zone, estimating the total number of people, the proportion that are likely to be exposed to the flood and the proportion of those exposed who are likely to be injured or killed during a flood. The results for each zone are combined to give an overall risk for each flood cell and/or community. The information needed for each part of the process is described, and the research needed to provide the required information is identified.



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# 1. PROJECT OVERVIEW

## 1.1 Objectives and scope

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 proposed developments.

Thus this project will contribute to all three key objectives. 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.

The proposal for the project (Defra Form CSG7) is contained in Appendix A. The project supports the move towards the understanding and management of flood risks (Defra/Environment Agency 2002).

The beneficiaries of the project will include:

- Environment Agency flood warning and emergency response staff
- Defra and Environment Agency staff and others involved in the planning of new flood defences, particularly to raise awareness of the possible increase in flood risks to people resulting from the construction of defences
- Emergency planners

- The emergency services
- Local Authorities and others involved in flood emergency planning and responding to floods.

The objectives of Phase 1 are to identify the causes of death or serious harm to people as a result of flooding, and develop an overall framework and approach to the project. Phase 1 also identifies specific research needs to develop the methodology so that it can be implemented on a national scale, and these will be carried out in Phase 2.

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’.

## **1.2 Approach to the project**

The risk of death or serious harm to people may be broken down into the following probabilities:

- Probability of a flood
- Probability that people will be exposed
- Probability that those exposed will be killed/injured.

One outcome from the project will be a method for calculating the annual probability of death/serious injury for different ‘hazard zones’ in each flood cell that is suitable for mapping. To do this it will be necessary to combine information on factors that cause death/serious injury (for example, flow velocity and flood depth), population, exposure probability and social vulnerability.

The objective will be to derive practical relationships that can be implemented, rather than more precise relationships that are difficult to derive and map. There is a balance to be made between ease of implementation and accuracy/reliability of the result.

It is important that the project links with other planned and ongoing projects and strategies, including:

- The ongoing research on long-term health impacts of flooding, which is complementary to this project

- The Agency’s Flood Mapping Strategy. In particular, any mapping method developed under this project must be consistent with the overall mapping strategy
- Risk Assessment for Strategic Planning (RASP), which should provide information on flood hazard in areas protected by flood defences
- The Modelling and Decision Support Framework (MDSF), which facilitates data management and analysis for Catchment Flood Management Plans (CFMPs) and Shoreline Management Plans (SMPs).

In order to obtain information to develop the required relationships the following approach was adopted in Phase 1 of the project:

1. Identify causes of flooding from literature review
2. Identify established relationships between causes and effects, from literature
3. Undertake case studies to understand better the causes and effects
4. Develop prototype relationships, calibrated against information from known events.

Risk approaches are reviewed in order to establish an appropriate framework for the project, and risk criteria are reviewed in order to identify a suitable format for presentation of the results.

The objectives of this project are supported by the recommendations for the management of floodplains to reduce flood risk (Defra/Environment Agency 2003). Appendix C of this report, which covers flood hazard assessment for emergency planning, is reproduced herein in Appendix B.

### 1.3 Project tasks

The project tasks under Phase 1 are as follows:

Task number	Task
1	Literature review
2	Review of recent severe flooding in Europe
3	Review of risk approaches
4	Identification of factors leading to risks to people
5	Collate information on relationships between hazard and risk
6	Review of risk criteria
7(a)	Case studies
7(b)	Links between causal factors and risk
8	Risks to people and frequency of occurrence
9	Flood hazard data
10	Reporting including Phase 2 research needs

### 1.4 Structure of the report

The report is divided into the following sections:

- A summary of the factors leading to risks to people (Task 4) is contained in Section 2. This is based on information from the literature review (Task 1, contained in Appendix C) and European Flood review (Task 2, contained in Appendix D).

Reference is also made to the Case Studies, contained in Appendix E. Section 2 also reviews the link between risks to people and frequency of flooding (Task 8).

- The review of risk approaches (Task 3) and risk criteria (Task 6) are contained in Section 3. This provides guidance on how risks are assessed and presented, and forms the basis of the methodology developed in Section 5.
- Section 4 outlines existing research results relating flood hazard to the risk of death/serious injury (Task 5).
- The development of a method for assessing the risk of death/serious injury as a result of flooding is covered in Section 5.
- The method is summarised in Section 6, and the associated data and R&D requirements are covered in Section 7. This includes an assessment of existing flood hazard data (Task 8).
- The Terms of Reference for the project are given in Appendix A.

## **2. CAUSES OF LOSS OF LIFE AND SERIOUS HARM TO PEOPLE DURING FLOODS**

The purpose of this section is to describe the causes of loss of life and serious harm to people during floods.

Background to this section is given in Appendix C (which outlines research literature) and Appendix D (which reviews flooding in Europe that has led to loss of life). Further more specific information is given in the Case Studies in Appendix E.

### **2.1 Risk of loss of life**

The conditions which lead to a risk of injury or loss of life are summarised in this section, based on information on flood events from around the world. It should be appreciated that the number of deaths caused by flooding in the UK is relatively small compared to some other countries.

#### **General**

The flood conditions in which the risks of death are likely to be greatest are those where one or more of the following conditions exist:

- Where flow velocities are high
- Where flood onset is sudden as in flash floods, for example the Linton/Lynmouth floods in 1952, Big Thompson flood, USA, in 1976 and flash floods in Southeast China in 1996
- Where flood waters are deep
- Where extensive low lying densely populated areas are affected, as in Bangladesh, so that escape to high ground is not possible
- Where there is no warning (i.e. where there is less than, say, 60 minutes of warning)
- Where flood victims have pre-existing health/mobility problems
- Where natural or artificial protective structures fail by overtopping or collapse. Flood alleviation and other artificial structures themselves involve a risk to life because of the possibility of failure, for example dam or dike failure
- Where poor flood defence assets lead to breaches or flood wall failure, leading to high velocities and flood water loadings on people in the way
- Where there is debris in the floodwater that can cause death or injury
- Where the flood duration is long and/or climatic conditions are severe, leading to death from exposure
- Where there is dam failure.

#### **Risk of loss of life: Building collapse and related circumstances**

- Death rates in floods are high where buildings fail to provide a safe refuge or collapse
- Timber framed buildings, mobile homes, informal, temporary and fragile structures (including campsites and other tented dwellings) may give rise to significant loss of life or hazardous rescues.

### **Risk of loss of life: Being swept away**

- Pedestrians, many of whom may be unaware of the power of floodwaters, can be swept away. Experimental studies suggest that the safe limit (for adults) is a product of depth (metres) times velocity (metres/sec) in the range of 0.5 to 1.0
- The heavier the person the less the chance of being swept away
- Eighty percent of the estimated 200 deaths in Monterrey, Mexico in 1988 were attributed to attempts to ford the flooded river.

### **Exposure**

- People trapped in buildings or on the roofs of buildings may die from exposure. This is linked to the duration of a flood
- In addition to the dangers caused by debris, other types of pollution could cause risks to people, for example the release of dangerous chemicals.

### **Trapped in building/vehicle**

- Many deaths in floods occur because people attempt to drive through or away from floodwaters and get swept away or trapped in their cars; their cars either then get swept away as a result of positive buoyancy or stuck in the floodwater. Almost half of flash flood related deaths in the US are the result of people being trapped in vehicles (see Appendix D Section D.5.3)
- Deaths can occur where people are trapped in single story buildings, ground floor apartments, cellars or underground structures, such as railways or car parks which can pose a particular threat to life in urban areas. Although buildings are often a safe refuge during a flood, there are other risks to consider (see Appendix D Section D.5.4)
- Buildings where there is a particularly high risk of people becoming trapped during a flood include schools, hospitals and old peoples' homes.

### **Falling down manhole or similar**

- In flooded urban areas, people attempting to move about, particularly where floodwaters are turbid or discoloured, may fall down blown manholes, into excavations or into ditches.

### **Behaviour of individuals during floods**

An important but difficult to quantify factor is the behaviour of some individuals during floods. Deaths have occurred of people curious to see a flood, particularly on the coast where they have been swept away by wave action. "Flood tourism" is recognised as a problem elsewhere in Europe, see Appendix D Section D.2.

## **2.2 Factors contributing to serious and acute consequences of flooding on human health**

Many of the circumstances leading to serious harm to people are the same as those which result in loss of life. They can be categorised as below:

### **The people, community and their property**

- Where the pre-existing health status is low
- Where the population at risk is elderly
- Where there are particular types of property e.g. single storey bungalows
- Where there is limited or no previous flood experience and awareness of risk
- Where there are no coping strategies developed following previous flooding
- When it is necessary to leave home and live in temporary accommodation
- Where there are pre-existing health conditions and susceptibility
- Where community support is poor.

### **The flood**

- Where there are certain characteristics of the flood event (high depth and velocity, long duration, unexpected timing (middle of night, etc.))
- Where floods are sudden and without warning
- Where there are no flood warnings received or they were not acted upon.

### **Related to damage, etc**

- Where the amount and type of property damage and losses is of a certain character and high
- Where there is frustration and anxiety in dealing with insurance companies, loss adjusters, builders and contractors, etc.
- Where recovery is impeded by a range of factors beyond the control of the flood victims
- the clean-up and recovery process and associated household disruption.

### **Other factors**

- Where there is increased anxiety over the possible reoccurrence of the event
- Where there is a loss in the level of confidence in the authorities perceived to be responsible for providing flood protection and warnings
- Where there are financial worries (especially for those not insured)
- Where there is a loss of the sense of security in the home
- Where there is an undermining of people's place identity and their sense of self (e.g. through loss of memorabilia)
- Where there is disruption of community life.

Some of these factors relate to harm that may occur more than one week after a flood, and are therefore not directly relevant to this project.

### **2.3 The relationship between risk to life and frequency/magnitude of flooding**

Where floods are a frequent occurrence, the population will be more aware of flood risk and are therefore more likely to know how to respond when a flood occurs. The purpose of this section is to explore whether frequency of flooding has a significant impact on the risk of death/serious injury when a flood occurs.

At an aggregate level, data from Europe shows that flood-related deaths are declining, although the number (and probably the severity) of floods is increasing (Figure 2.1). This appears to be a perverse relationship, but it is related to improvements in flood forecasting and warning over the last three decades. Fewer floods now come unannounced, and in most circumstances both the population and the emergency services therefore have time to take evasive action and provide assistance respectively.

At any flood-affected location, those closest to the river or coast within a floodplain will be flooded more often (other things being equal), by the minor floods that occur frequently. Those at the edge of the floodplain will be flooded less frequently, and only by the more severe floods (although they may not be severe for them, since they will be flooded by water at the margin of the floodplain which is shallow and generally very slow moving).

Thus the impact of a very infrequent event (say the flood with an annual probability of 1%) will be different for different people. For some it will be a repeat of flooding that affects them quite often, because they live in the 10% flood outline, but with flooding at a greater depth and duration. However for others it will be a once in a lifetime event (if, for example, they live at the edge of the 1% floodplain). The latter group will not generally experience repeated flooding.

This means that there is no inherent reason for the person affected to be affected differently whether they are flooded by a 100-year flood or a 10-year flood. A 100-year flood will be more severe for some people, particularly those that live in the “floodway” where depths will be greater than average and flood velocities can be high.

Major floods therefore may not present much extra effect on loss of life for individuals who are flooded relatively frequently. However they do affect more people, and some of these will be affected severely. A rare event is also more likely to cause loss of life because it is likely to be deeper in parts of the affected floodplain, other things being equal.

There may be a difference in major urban events and other ‘flash’ floods. The rare events will have larger volumes of localised rain, causing greater flood flows. Anyone caught in the floodwaters of these events will be at greater risk than from more minor events. A rare thunderstorm type event – Lynmouth 1952 - is more likely to have some of its floodwater moving more quickly, because it is deeper. In addition, flash floods are local and those affected may not have been flooded before.

Another type of infrequent event that affects people who are not flooded more frequently by smaller floods is that of defence overtopping or failure. In such cases the people affected may be at greater risk because their level of awareness that flooding can occur may be low.

A different dimension to this is the effect of repeat flooding on flood victims. Most empirical evidence suggests that the effect on their health is not very significant, whereas depth and warning time are more significant (Table 2.1) (Floyd and Tunstall, 2003). But what we do know from research is that those who have more experience of flooding are much more likely to take flood mitigating actions on their own accord. Some of these will reduce the risk to life and acute effects (such as when they buy a

boat, or invest in equipment to stop water entering their houses, see Table 2.2). They also are more realistic about the extent that they will be flooded again, showing less optimism (i.e. expecting fewer floods in the future than experienced in the past) than those with no experience of being flooded. They are more aware of flood risks and have greater knowledge of how to respond.

It is concluded from the above discussion that the ‘framework’ for the project should take into account the following:

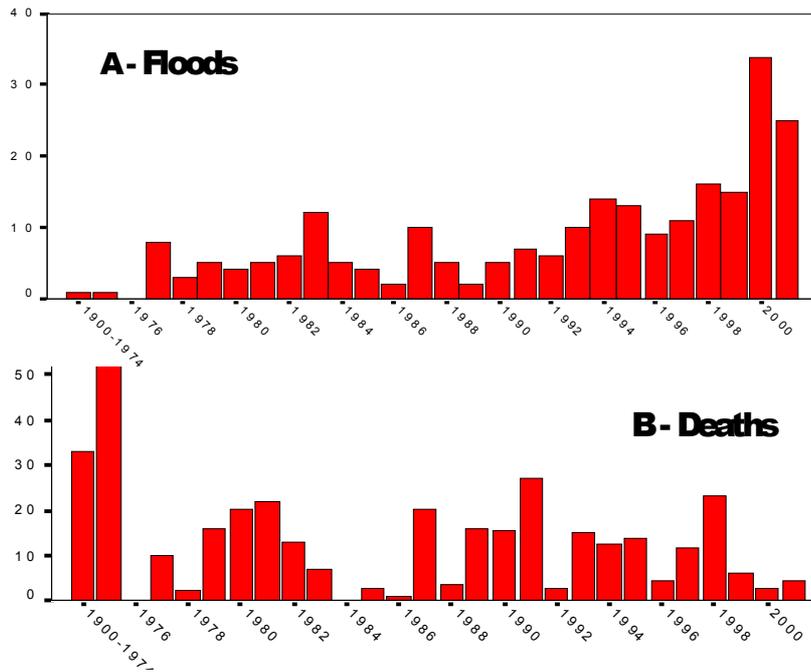
*To the individuals affected, rarer (and therefore larger) floods are not necessarily or inherently more dangerous, except when these take the form of ‘flash floods’, for example as major thunderstorm events in urban areas (see below) or where a defence collapses or is overtopped.*

But:

- More people are generally affected by the rarer floods, because they cover a wider area
- Rarer fluvial events will tend to have a longer duration and this could mean those affected are exposed to risks for a longer period of time
- Rare ‘flash floods’ caused by intense localised rainstorms, such as urban drainage related floods or the Lynmouth type event, are likely to be more dangerous to the individual. This is because the difference between small scale and common events and these rarer floods is the difference between minor ponding of small rainfall amounts and large, deep and fast-flowing floods.

This means that a mapping exercise to locate areas of greatest risk of loss of life and acute harm needs to focus on:

- The geographical extent of the event and thus the number of people affected
- The size of the ‘floodway’ where depth and flood water velocities are high
- Areas where rare ‘flash flood events’ are likely, such as steeply sloping catchments, steep and heavily urbanised areas, or areas behind coastal and fluvial flood defences.



**Figure 2.1** The number of floods and number of flood-related deaths in Europe (from World Health Organisation data).

**Table 2.1** Factors influencing the health impacts of floods (listed in order of decreasing significance)

Significance	Post Traumatic Stress Syndrome	General Health Questionnaire
Highly significant	1. Problems within insurers	1. Problems with insurers
	2. Gender	2. Gender
	3. Age	3. Problems with builders
	4. Warning time	4. Rented accommodation
	5. Prior health	
	6. Flood Depth	
	7. Rented accommodation	
	8. Years since flood	
	9. Evacuation	
Some significance	1. Problems with builders	Contamination
	2. Flood awareness	Age
	3. Contamination of flood waters	Prior health
	4. Income	Vulnerable housing
		Flood Depth
		Years since flood
		Flood awareness
		Warning time

**Table 2.2 The proportion of residents in the lower Severn floodplain adopting at least one risk reducing response to the flood hazard that they face**  
(Penning-Rowsell *et al*, 1986)

Length of residence (and hence experience)	Flood risk: Very low	Flood risk: Low	Flood risk: Medium	Flood risk: High
> 25 years	27%	36%	41%	74%
5-25 years	18%	28%	34%	53%
< 5 years	20%	25%	31%	32%

### 3. RISK ASSESSMENT AND RISK CRITERIA

#### 3.1 Approach to risk assessment

##### 3.1.1 Nature of risk

The use of the word risk within the field of flood and coastal defence is commonplace. Defra's Project Appraisal Guidance Series refers to risk based methods for appraisal and specifically covers risk in **FCDPAG 4 - Approaches to Risk**, which states that risk depends on a combination of both the likelihood and consequences of an event. This is not novel and reflects definitions used across the risk field. By way of example, the Royal Society (1992) came to the view that risk could be defined as:

*“a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence”;*

and, a similar definition is used by the British Standard Institution (1996):

*“the combination of the likelihood and consequence of a specified hazardous event occurring”.*

The following definitions have been adopted by DG SANCO (European Commission: Directorate-General for Health & Consumer Protection) and are being used across a range of activities which present risks to EU citizens:

*Risk – the probability and severity of an adverse effect/event occurring to man or the environment following exposure, under defined conditions, to a risk source(s)* (European Commission, 2000).

For completeness, the associated definition for hazard is:

*Hazard – the potential of a risk source to cause an adverse effect(s)/event(s).*

In the UK the revised Departmental Guidance for Environmental Risk Assessment and Management (DETR 2000), also known as 'Green Leaves II', use 'risk' and 'hazard' with the following meanings:

*Risk – a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequence of the occurrence.*

*Hazard - a property or situation that in particular circumstances could lead to harm*

These views of risk are reflected in a major definition study undertaken as part of the Defra/Environment Agency Risk & Uncertainty Theme. This reviewed the principles, definitions and tools of risk, uncertainty and performance in flood and coastal defence. The report (Defra/Environment Agency 2002) states:

*“Risk, therefore, has two components - the chance (or probability) of an event occurring and the impact (or consequence) associated with that event.”*

That report also discusses the use of the ‘source – pathway – receptor’ model for characterising flood risk systems.

Whilst the merits of these and similar definitions may be debated, we propose to use the term risk to mean *the probability and severity of an adverse effect/event occurring to man or the environment following exposure, under defined conditions, to a risk source(s).*

As can be seen from these definitions, in the context of this study, the risk source is floodwater, the hazard is the potential to cause direct injuries and the risk is the likelihood/probability<sup>1</sup> that such a potential is realised.

### 3.1.2 Risk assessment

The procedure by which risk is determined is ‘risk assessment’ where this may be defined as:

***Risk Assessment – a process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of an adverse effect(s)/event(s) occurring to man or the environment following exposure under defined conditions to a risk source(s).*** (European Commission, 2000)

As can be seen, a risk assessment involves analysis of the hazard and derivation of the associated risk. The DG SANCO report further defines a risk assessment as comprising hazard identification, hazard characterisation, exposure assessment and risk characterisation and it is this broad approach which will be followed in this study. This framework as illustrated in Table 3.1.

**Table 3.1 Risk assessment framework**

Risk assessment stage	Definition <sup>1</sup>
Hazard identification	The identification of a risk source(s) capable of causing adverse effect(s)/event(s) to humans or the environment, together with a qualitative description of the nature of these effect(s)/event(s).
Hazard characterisation	The quantitative or semi-quantitative evaluation of the nature of the adverse health effects to humans and/or the environment following exposure to a risk source(s). This must, where possible, include a dose response assessment. <sup>2</sup>
Exposure assessment	The quantitative or semi-quantitative evaluation of the likely exposure of man and/or the environment to risk sources from one or more media.
Risk characterisation	The quantitative or semi-quantitative estimate, including attendant uncertainties, of the probability of occurrence and severity of adverse effect(s)/event(s) in a given population under defined exposure conditions based on hazard identification, hazard characterisation and exposure assessment.

Notes: <sup>1</sup>Definitions taken from European Commission (2000)

<sup>2</sup>A ‘dose response assessment’ examines the relationships between the scale of the exposure and the scale of the adverse effects - such those considered in Section 4.2.

<sup>1</sup> It should be noted that ‘likelihood’ relates to chances per year (i.e. expected frequency) whereas probability is the chance of occurrence within a specified time frame or per event

This is similar to the framework for risk assessment recommended in Green Leaves II (DETR 2000) but the terminology differs slightly. Green Leaves II and Defra/Environment Agency (2002) adopt the stages of ‘Hazard identification’, ‘Identification of consequences’, ‘Magnitude of consequences’, ‘Probability of consequences’ and ‘Significance of risk’. These are structured within a tiered framework to encourage screening and prioritising of risks before moving to detailed quantitative analysis where necessary. For completeness, Table 3.2 provides a comparison of the two sets of stages.

**Table 3.2 Environmental risk assessment framework (DETR, 2000)**

Environmental risk assessment stage	Equivalent risk assessment stage (from Table 3.1)	Comment
Hazard identification	Hazard identification	No significant difference.
Identification of consequences	Hazard characterisation	Analysis of consequences is essentially the same as that envisaged for ‘hazard characterisation’.
Magnitude of consequences		
Probability of consequences	Exposure assessment  Risk characterisation	The DG SANCO approach involves two stages to estimating risks - the conditional probability of the consequences is determined which is then combined with the probability of occurrence of the hazard. In contrast, the environmental risk assessment framework combines all factors in a single calculation step.
Significance of the risk	Not specified	The environmental risk guidelines acknowledge (explicitly) that it is important to present the results of risk assessment work in context.

Although there are some slight differences in defining the key stages, it can be seen that both frameworks follow the same basic approach. On this basis, it would seem that the use of the DG SANCO approach is not unreasonable - particularly as the focus of the study is on direct risks to people. However, should the methodology be carried forward (to Phase 2) it would be relatively straightforward to redefine the key stages in accordance with the Environmental Risk Guidelines.

### **3.1.3 Application of risk assessment framework**

#### **Hazard identification**

Within the context of this study, the risk source is floodwater and the hazard is the potential of that floodwater to cause physical injury or death during or immediately after (i.e. within days) flooding. The project is specifically concerned with these short-term physical effects, and not the longer term physical & psychological effects which are more the focus of other studies.

### **Hazard characterisation**

From Table 3.1, it can be seen that the purpose of this stage of the risk assessment is to evaluate the effects of being exposed to the risk source. In simple terms, the effects may be characterised by the expression:

$$E = f(F, L, P)$$

where: E = nature/extent of effects (on those exposed)  
F = flood characteristics (depth, velocity, etc.)  
L = location characteristics (inside/outside, nature of housing)  
P = population characteristics (age, health, etc.)

It may well be the case that ‘dose response’ relationships are derived for different groups of people (for example, those outdoors, those indoors and those in vehicles).

### **Exposure assessment**

Given a ‘dose response’ assessment from above, the exposure assessment focuses on the relationship between the presence of the floodwaters and the probability that the adverse effects are realised. In other words, how likely (probable) is it that given the presence of floodwaters, that people will actually be exposed? For example, if everyone is indoors and upstairs, then no-one will be exposed (directly) to the risk source. As can be seen, this stage really examines the conditional probabilities that someone present will be exposed to the risk source.

### **Risk characterisation**

The final step of the risk assessment is to combine:

- the likelihood/probability of a flood (to produce the risk source)
- the probabilities that people will be exposed (based on the nature/size of population present and associated probabilities of exposure)
- the probabilities that those exposed will be injured.

#### **3.1.4 Presentation of results**

##### **Use of individual risks, societal risk and probable loss of life values**

When considering risks to people, however, there is often a distinction drawn between the risk to an individual (*individual risk*) and the risk to groups of people (*societal risk*). Examples of more formal definitions (from IChemE, 1992) of these are:

*Individual Risk is the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards; and Societal Risk is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.*

In some cases, it is also useful to consider a third measure of risk based on the product *frequency x consequence*. Such expressions represent the statistical loss over time (sometimes referred to as expected value or the probable loss). By way of example, the risks to residents living behind a coastal defence may be presented as follows:

- the individual risk to an individual resident is 1 chance in 100,000 per year of being drowned as the result of a flood
- the societal risk to the residents may be characterised as follows: the chances of 1 drowning or more, 10 drownings or more and 100 drownings or more are 1 in 100,000 per year, 1 in 300,000 per year and 1 in 1 million per year respectively
- the probable loss of life (PLL) amongst the residents is (on average) one life per thousand years for every 100 people in the flood risk area.

It is important to define the group of people to which the risks are applied. In this report, the group of people is the people at risk of flooding (i.e. the population of a floodplain or hazard zone within the floodplain). It is not the total population. Thus, if the individual risk is 1 chance in 100,000 per year and there are 5 million people living in the floodplains of the UK, the probable loss of life is (5,000,000/100,000), or 50 people per year on average.

Of note is that, from a technical ‘risk’ perspective, the associated risk to society (expressed in terms of PLL values) can be determined from the expression:

*level of individual risk x number of people exposed*

Using this approach, and invoking a ‘value for a life’, it is then possible to compare the costs and benefits (in human health terms at least) associated with different risk management strategies. Of course, this methodology is often used to test whether a particular measure meets the principles of ALARP, ALARA, etc. (HM Treasury, 1996) and, indeed, is recommended for use in Regulatory Appraisal (Cabinet Office, 1996).

### **Presentation of results**

The presentation of risk results is problematic. Within the flood and coastal defence field, the difficulties are compounded by the use of ‘return periods’ which are not always easily understood. It is worth noting that, in the planning guidance on flood risk, PPG25 (DTLR, 2001), the use of return periods has been replaced by percentages of the form: ‘annual probability of flooding is 1.0%’. Furthermore, in a recent report by the Institution of Civil Engineers (2002) it is stated that:

*“... flood engineers must also improve their attempts to communicate with the public and scrap references to return periods for floods and start talking about ‘odds’ of a major flood happening.”*

Although this comment should be borne in mind, we query whether the use of ‘odds’ will be better understood. To give an example: a flood event with a return period of 100 years (i.e. one that has a 1 chance in 100 per year or a 1% annual probability) has:

- 10% (i.e. 1 in 10) chance of happening within the next 10 years
- 33% (1 in 3) chance of happening in the next 40 years
- 50% (50:50) chance of happening in the next 70 years.

A layperson who has just been flooded by a 100 year event may consider that it will not happen again for 100 years and therefore ‘feel safe’. On the other hand, a person who has lived in their house for three years and within that time has experienced a similar flood (a 100 year event) may consider that they will experience the same flood every three years.

## 3.2 Risk results and criteria

### 3.2.1 Introduction

Most people would accept the proposition that there are three broad categories of risk:

- those that are so high as to be unacceptable/intolerable
- those that are so low as to be acceptable/negligible
- those in between where consideration needs to be given to the various trade-offs between the risks and the benefits.

Over the years, there has been a considerable amount of work undertaken to identify where the associated limit values should be defined, taking account of such factors as the nature of the risk, the uncertainties in the calculation of that risk, historical data on accidents, degree of aversion to multi-fatalities, etc.

In broad terms, a distinction must be drawn between individual risk (the risk to an individual) and societal risks (the risk to society at large). For individual risks, it is common practice to ‘anchor’ criteria against historical data on other risks (such as those associated with driving, working, smoking, etc.). Setting criteria for societal risks has proved to be more complex (Ball and Floyd, 1998) due to the need to account for very remote (i.e. extremely unlikely) events with extreme consequences (such as major nuclear or chemical disasters).

### 3.2.2 Individual risks in the UK

Within the UK, statistics are gathered by various authorities on the numbers of deaths by different causes. Table 3.3 provides an indicative summary of the risks to the average UK citizen.

**Table 3.3 Individual risks in the UK**

Risk Level	Risk
1 chance in 100 per year	Risk of dying at age 60
1 chance in 1,000 per year	Risk of employee being killed in high hazard industry
1 chance in 10,000 per year	Risk of being killed in car accident Risk of employee being killed at work (construction industry)
1 chance in 100,000 per year	Risk of being murdered Risk of being killed as a pedestrian
1 chance in 1 million per year	Risk of contracting (non-BSE linked) CJD Winning the lottery jackpot (10 tickets/year)
1 chance in 10 million per year	Risk of being killed by lightning

Notes: <sup>1</sup>Various sources but Annex 4 to HSE (1999): **Reducing Risks, Protecting People** provides a range of risk statistics.

### 3.2.3 Individual risk criteria in the UK

In the UK, there have been various Government reports advancing individual risk criteria, often with reference to data of the sort presented in Table 3.2. Particular attention has been given to the *Tolerability of Risk* report published in 1988 (and revised in 1992) by the HSE in the wake of the Sizewell B Inquiry.

Briefly, this advanced the following limits for the annual individual risk of death:

- 1 in 1,000 represents the upper limit of tolerability (i.e. on the borderline of unacceptability) for workers in ‘risky’ occupations (such as deep sea fishing)
- 1 in 10,000 represents the upper limit of tolerability for a member of the public
- 1 in one million represents the lower limit of tolerability for all (i.e. lower risks would generally be regarded as acceptable or negligible).

This approach to setting limits has been reviewed and endorsed by other Government departments (HM Treasury, 1996 and POST, 1996). More recently, the issue of risk acceptability has been revisited by HSE in a Discussion Document (HSE, 1999) which, again, reaffirms the limits outlined above.

### 3.2.4 Individual risk levels by risk source

An indication of individual risk levels by risk source is presented in Table 3.4.

**Table 3.4 Individual risk levels by hazard**

Risk Source	Annual Risk of Death limited by Current Targets						Nature of Hazard
	1 in 100 million	1 in 10 million	1 in 1 million	1 in 100,000	1 in 10,000	1 in 1,000	
Radon				—————◆			‘Natural’ hazards
Flooding	—————◆						
Chemical plant safety (workers)			—————◆				‘Man-made’ hazards with acute effects
Major accidents (public)	—————◆						
Radioactive waste	—————◆						‘Man-made’ hazards with long term cancer effects
Chemicals in everyday use	—————◆	?					
Tolerability (for members of the public)	Acceptable		Tolerable		Unacceptable		
Legend:	◆ ◆	Upper limit for risk tolerability (for each hazard) as currently proposed or in use					
	—————	Risk levels associated with each hazard (with limit in place)					

As can be seen from Table 3.4, there is a tendency to set more stringent risk limits for ‘man-made’ hazards than for ‘natural’ hazards (i.e. flooding and radon). For ‘man-made’ hazards, there is greater aversion to what is commonly referred to as the ‘dread’

risk of cancer (with particular reference to the European Commission's policy on chemicals in everyday use).

### **3.3 Conclusions**

- The recommended approach to risk assessment combines the probability of a flood with the probability that people will be exposed to the flood and the probability that those exposed will be injured
- Risk may be presented in societal terms (i.e. the estimated number of deaths per year caused by flooding in a unit of land, for example a flood cell) or in individual terms (i.e. the annual probability that an individual in a unit of land will die as a result of flooding)
- It is suggested that the upper limit of risk tolerability for floods is of the order of one chance in 100,000 per year (and this is discussed further in Section 5.7.1).

## 4. RELATIONSHIPS BETWEEN FLOOD CHARACTERISTICS AND ADVERSE EFFECTS

### 4.1 Hazard characterisation and exposure assessment

This section is focused on the two stages which provide the quantitative (if possible) relationships between the flood characteristics and the effects of concern. Within the risk assessment framework, there are two steps:

- **hazard characterisation** which was defined as: *the quantitative or semi-quantitative evaluation of the nature of the adverse health effects to humans and/or the environment following exposure to a risk source(s). This must, where possible, include a dose response assessment; and*
- **exposure assessment** which was defined as: *the quantitative or semi-quantitative evaluation of the likely exposure of man and/or the environment to risk sources from one or more media.*

A set of relationships may be derived to calculate the probability of death or serious injury from a combination of exposure probability and probability that those exposed will be killed or injured. There has been some research in this area and this section summarises some of the established relationships between causes and effects. Further quantitative analysis for the exposure assessment is presented in Section 5.

Flood risk can also be calculated by looking at historical experiences. This does not, however, give the link between risk and the variables presenting the hazard that we are looking for. For example, the risk of death from flooding in New South Wales between 1981 and 1986 was 0.2 chances per million person years. This means that for any one person, there was 1 chance in 5 million of being killed as a result of flooding in any one year (1 million / 0.2). Over 20 years the risk of death from this cause increases to 1 chance in 250,000 and over 50 years the risk increases to 1 chance in 100,000. These figures are based on the whole population, not just the floodplain population.

The approach recommended in this report is to derive an overall methodology based on relationships between risk source and effect, and ‘calibrate’ the method using information from historic floods.

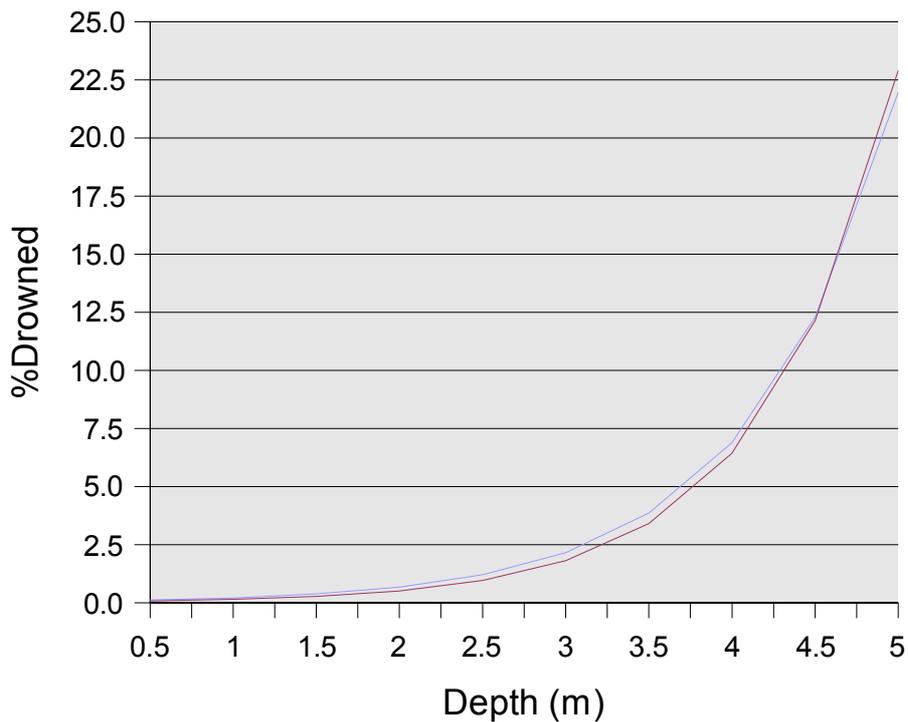
### 4.2 Depth and velocity relationships

#### 4.2.1 Depth relationships

For people outdoors (and in cars), water depths of, say, 2m are obviously life threatening. For people in two storey dwellings depths of, say, 5m would be critical. Waarts (1992, quoted in Jonkman *et al.* 2002) has derived the following two empirical expressions (based on the 1953 floods in Holland) which give similar results. The associated results are illustrated in Figure 4.1:

$$\begin{aligned}\delta_{h1} &= 0.665 \cdot 10^{-3} \cdot e^{1.16 \cdot h} \\ \delta_{h2} &= 0.4 \cdot 10^{-3} \cdot e^{1.27 \cdot h}\end{aligned}$$

where:  $\delta_{hi}$  mortality: fraction of the inhabitants of the area drowned ( $i = 1,2$ )  
 $h$  water depth (metres)



**Figure 4.1 Examples of relationships between %drowned and depth**

#### 4.2.2 Depth and rate of rise

HKV (2000, quoted in Jonkman 2002) provides the following depth and rate of rising water – mortality relationship:

$$f_{ng} = \text{MIN}\{\text{MAX}[8.5 \exp(0.6 h - 6) - 0.15, 0], 1\} \cdot \text{MIN}\{\text{MAX}[8.5 \exp(1.2 v - 4.3) - 0.15, 0], 1\}$$

and

$$f_{ng} = 0 \quad \text{For } h < 3\text{m or } v < 0.3 \text{ m/hr}$$

$$f_{ng} = 1 \quad \text{For } h > 6.25\text{m and } v > 2 \text{ m/hr}$$

where

$$f_{ng} \quad \text{mortality (probability of drowning)}$$

$$v \quad \text{rate of rising of the water (metres / hour)}$$

The equation is based on the analysis of Waarts of the 1953 flood.

Using the above equation, the risk of death is zero for flood depths less than 3m and rate of rise less than 0.3m per hour, but is 100% for flood depths greater than 6.25m and rate of rise greater than 2m per hour. Whilst this clearly relates to a specific situation (ie data from the 1953 flood) it indicates a possible format for combining these variables.

#### 4.2.3 Depth and velocity

Combinations of depth and velocity are generally considered to be the fundamental cause of death/serious injury during floods.

### Impacts of depth and velocity on humans

Models derived for depth-velocity functions usually use the simple product: depth x velocity. Abt *et al* (1989) used people in a flume to test the velocity and depth that cause instability. The developed relationship is expressed as:

$$P.N. = [e^{0.022(G \cdot L/1000) + 1.09}]^2$$

Where

- P.N. product number of stream velocity and depth (ft<sup>2</sup>/s)
- G weight of person (pounds)
- L height of person (feet)

Thus a man weighing 80kg and 1.85m tall is likely to fall over when the product of velocity and depth equals or exceeds about 1.4 (e.g. 1m depth, velocity 1.4m/s).

Lind and Hartford (2000, quoted in Jonkman 2002) use a theoretical function calibrated with the tests of Abt *et al*. The relationship expresses the stability failure function as a depth – velocity relationship. There is however concern that the experimental arrangements used by Abt *et al* may not be representative of conditions during an actual flood.

Research used by the Agriculture and Resource Management Council of Australia and New Zealand (2000) presents hazard estimates based on depth, velocity and evacuation time. In this research, ‘hazard’ refers not only to instability of a person in water but also to the stability of foundations, poles, grass and earth etc. The degree of hazard is split into four classifications: low, medium, high and extreme. The categories differentiate between such factors as whether a person is able to stand up and wade in the water, whether adequate warning time is given and if vehicle evacuation is possible. Graphs of hazard as a function of depth and velocity and of hazard as a function of evacuation time are given. Sample values are given below:

Upper limit of high hazard zone:

- Depth = 1.2m combined with Velocity = 0m/s
- Low depth combined with Velocity = 1.5m/s

Limit of wading for adults:

- Depth = 1.5m combined with Velocity = 0m/s
- Depth = 0.5m combined with Velocity = 2m/s

The degree of hazard is changed by evacuation time (for example, if there is plenty of time for evacuation the hazard reduces, but if there is not enough time the hazard increases).

The method is described in more detail in Appendix B.

Some recent work on the relationship between depth and velocity has been carried out by the Flood Hazard Research Centre by field tests involving a stunt man. However it has proved difficult to provide the full range of depths, velocities and people characteristics (weight, height, etc) to achieve a reliable and useful set of results.

### **Impacts of depth and velocity on buildings, etc.**

Vrouwenvelder (1997, quoted in Jonkman 2002) models fatality caused by collapsed buildings due to wave attack, based on the structural strength of buildings. The relationship uses:

- probability of storm (1 for a coastal flood, 0.05 for a river flood)
- probability of collapsing of a building given a storm
- material factor
- flood water depth in metres
- shelter factor

Vrouwenvelder (1997, quoted in Jonkman 2002) models drowning due to dike breach. The relationship uses:

1. The probability of dyke breach nearby a residential area
2. The fraction of houses at a dyke breach that are washed away due to high stream velocities (it is assumed that the area destroyed has a surface of the quadrate of the width of the breach)

Similarly, Vrouwenvelder (1997, quoted in Jonkman 2002) models total fatality using all the factors from the equations for fatality from collapse of buildings and from dike breach, plus:

1. the fraction of the people evacuated
2. the number of inhabitants for a segment of the area.

These relationships require information on property types and location, and are likely to be difficult to implement on a national scale.

### **Combined relationships and impacts**

Jonkman (2001, quoted in Jonkman 2002) provides a general formula for loss of life for sea and river floods in the Netherlands based on:

1. the Waarts relationship for probability of drowning as a function of depth
2. the effect of velocity on buildings and humans
3. probability of successful evacuation based on the time available for evacuation

The relationship uses Abt et al.'s research on human instability under different water velocities. The function represents mortality both for people inside and outside buildings. Evacuation time, water depth and stream velocity are all functions of the location inside the flood risk area.

Results from Reiter, 2000 (as shown in Table 4.1) provide further estimates of the combined impacts of depth and velocity on both people and buildings.

**Table 4.1 Damage potential of floodwaters**  
(from RESCDAM - Reiter, 2000)

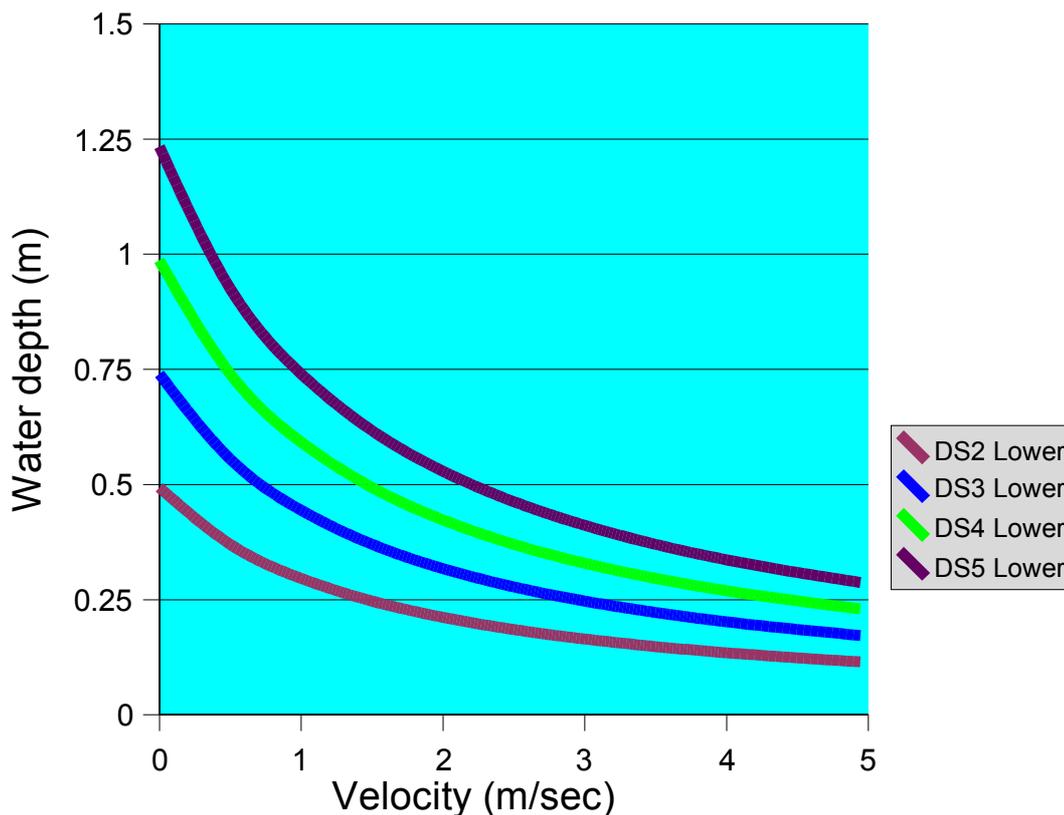
Damage to:	Damage parameter $D \times v$ ( $m^2/sec$ )		
	Low	Medium	High
Children	< 0.1	0.1 – 0.25	> 0.25
Adults	< 0.3	0.3 – 0.70	> 0.70
Personal cars	< 0.9	0.9 – 1.50	> 1.50
Lightly constructed houses	1.3	1.3 – 2.50	> 2.50
Well constructed wooden houses	< 2.0; $v > 2.0$ m/s	2.0 – 5.0; $v > 2.0$ m/s	> 5.00
Brick houses	< 3.0; $v > 2.0$ m/s	3.0 – 7.0; $v > 2.0$ m/s	> 7.00

Recent research (Kelman, 2002) provides a detailed analysis of the impacts of depth and velocity on residential properties in eastern England. The research proposes a damage scale (DS) ranging from DS0 to DS5 as presented in Table 4.2.

**Table 4.2 Damage scale proposed by Kelman (2002)**

Damage	Description
DS0	Water does not contact building
DS1	Water contacts building but does not enter
DS2	Water infiltrates building and/or some external damage
DS3	Water or debris enter building through (closed) door/window
DS4	Structural damage to walls lead to water/debris entry
DS5	Structural collapse and beyond repair

Kelman provides some data which enable Figure 4.2 to be constructed to illustrate the combined impact of depth and velocity on buildings. The lines represent the lower bounds for DS2, DS3, etc.



**Figure 4.2 Damage to buildings (based on Kelman, 2002)**

### 4.3 Flood warning and evacuation

Clearly the provision of timely flood warnings and, if necessary, prompt evacuation will substantially reduce the expected impacts in the event of a flood.

Heinje et al. (1996, quoted in Smith & Ward 1998) aim to provide a comprehensive performance-based assessment of flood warnings on the basis that there are four principal factors which contribute to an effective flood warning system:

1. Proportion of the population at risk that is warned with sufficient lead time to take action (R).
2. Proportion of residents available to respond to the warning (PRA).
3. Proportion of households able to respond to the warning (PHR).
4. Proportion of households who respond effectively (PHE).

The product of these proportions gives the figure for overall performance

Although dams are beyond the scope of this study, research into the effects of dam breaks highlights the need for effective flood warnings. Graham (1999, quoted in Jonkman 2002) models loss of life due to dam failure. Fatality rates are tabulated and are based on:

1. Flood severity. This is given by water depth and the depth-velocity product.
2. The amount of warning. There are three categories of warning time: no warning, some warning (15 – 60 minutes) and adequate warning (>60 minutes).

### 3. Understanding by the population of the magnitude of the risk

The research is based on 40 historical dam breaks.

Graham and Brown for the US Bureau of Reclamation (1989, quoted in Graham 2000) develop procedures for estimating loss of life from dam failure. The rules developed are:

For areas receiving less than 15 minutes' warning:  
Loss of life = 0.5 (people at risk)

For areas receiving between 15 and 90 minutes' warning:  
Loss of life = (people at risk)<sup>0.6</sup>

For areas receiving more than 90 minutes' warning:  
Loss of life = 0.0002 (people at risk)

Thus is an area with 10,000 people, the loss of life would be 5,000, 250 and 2 respectively for the three categories listed above.

DeKay and McClelland (1991, 1993, quoted in Graham 2000) expanded on the research by Graham and Brown and developed relationships for dam break and flash floods. Their procedure shows that loss of life is related in a non-linear fashion to the number of people at risk.

In high-force situations (such as a canyon):  
Deaths = (number of people at risk) / [ 1 + 13.277 (PAR<sup>0.440</sup>)e<sup>[2.982(WT) - 3.790]</sup> ]

In low-force situations (such as a plain):  
Deaths = (number of people at risk) / [ 1 + 13.277 (PAR<sup>0.440</sup>)e<sup>[0.759(WT)]</sup> ]

Where

PAR is the number of people at risk

WT is the warning time in hours (from the initiation of warning to when the water reaches the people).

#### 4.4 Seawall overtopping

Almost every year there are one or more deaths caused by people being washed into the sea by wave action. Whilst very different in character to the flood mechanisms that cause death/injury to people discussed elsewhere in this report, the frequency of this occurrence means that it should not be ignored.

HR Wallingford (1979, 1999) researched the effects of overtopping of seawalls for structure design purposes. Peak overtopping discharges rather than average discharge represents the most hazardous events for pedestrians and vehicles moving behind the wall. For certain seawall designs, the peak individual discharge may be the event initiating damage to, or failure of, the defence.

Peak overtopping discharges are quoted as:

1. For a person walking immediately behind seawall with a little discomfort:  
 $Q < 4 \cdot 10^{-6} \text{ m}^3/\text{s}/\text{m}$
2. For a person walking immediately behind seawall with little danger:  
 $Q < 3 \cdot 10^{-5} \text{ m}^3/\text{s}/\text{m}$  (= 0.03 l/s/m)
3. For a car to pass immediately behind seawall at high speed:  
 $Q < 1 \cdot 10^{-6} \text{ m}^3/\text{s}/\text{m}$
4. For a car to pass immediately behind seawall at low speed:  
 $Q < 2 \cdot 10^{-5} \text{ m}^3/\text{s}/\text{m}$
5. For a house located immediately behind seawall to suffer no damage:  
 $Q < 1 \cdot 10^{-6} \text{ m}^3/\text{s}/\text{m}$
6. For a house located immediately behind seawall to suffer some damage:  
 $Q < 3 \cdot 10^{-5} \text{ m}^3/\text{s}/\text{m}$  (= 0.03 l/s/m)  
[Q greater than this level will result in structural damage].

HR Wallingford (1979)

Safe overtopping limits for pedestrians and vehicles as researched by Franco et al. (1994) are reported. An overtopping volume was “safe” if it created less than 10% chance of a person falling over, or “very dangerous” if greater than 90% chance. The limits vary with structure type. A given volume overtopping a vertical structure would be more dangerous than the same volume overtopping an embankment with sloping faces.

Safe limit for overtopping volume that a person can withstand:

- From experiments with volunteers:  $0.05 \text{ m}^3/\text{m}$
- From model test of vertical seawall:  $0.1 \text{ m}^3/\text{m}$
- From model test of horizontally composite seawall:  $0.75 \text{ m}^3/\text{m}$

In summary, all structures become dangerous for pedestrians when the largest overtopping event exceeds  $0.04 \text{ m}^3/\text{m}$ . All structures become dangerous for vehicles driven at any speed when the largest overtopping event exceeds  $0.06 \text{ m}^3/\text{m}$  (HR Wallingford 1999).

## 5. DEVELOPMENT OF A METHODOLOGY FOR ASSESSING FLOOD RISKS

### 5.1 Overview

As previously indicated (see Section 3.1.3), there are three broad sets of characteristics which will influence the degree of (immediate) harm in the event of a flood:

- flood characteristics (depth, velocity, etc.)
- location characteristics (inside/outside, nature of housing)
- population characteristics (age, health, etc.).

These are discussed in more detail below.

### 5.2 Flood characteristics

There is broad agreement that the degree of hazard associated with floodwater is primarily associated with depth and velocity. Table 5.1 presents a list of other parameters which might be considered relevant together with comments on how these might be considered in the analysis.

**Table 5.1 Potential flood characteristics of relevance (apart from depth and velocity)**

Parameter	Comment
Speed of onset and flood warning	The speed of onset and flood warning are important factors. However, these affect the probability that people will be exposed rather than the intrinsic hazardous properties of the floodwaters (i.e. speed and depth).
Flood duration	Within the UK, flood durations are likely to range from several hours to a few weeks. Whilst one could advance the view that someone trapped in their homes in a winter flood for several days is more likely to suffer hypothermia, it is considered that duration is unlikely to be a significant factor for immediate serious injuries or worse.
Debris	Fast moving floodwaters carrying debris present a greater threat (to both people and structures) than those with no debris. Sources of (large) debris include trees, cars, caravans, etc. This factor needs to be accounted for.
Nature of floodwater	Different types of floodwater have varying degrees of damage potential. It is generally acknowledged that seawater causes more damage to buildings than river water. Sewage contamination would be expected to present an increased risk of disease. However, in terms of short-term physical effects, the nature of the floodwater is unlikely to be a significant factor.

**Table 5.1 Potential flood characteristics of relevance (apart from depth and velocity) continued**

Parameter	Comment
Level of flood risk and presence of defences	The presence and condition of flood defences together with the past flooding record and predictions of future flooding all relate to the risk of the flood event occurring, and are therefore taken into account in the estimation of flood probability. This includes breaching of defences, where the probability of failure is equal to the probability of the event. The flood hazard is expressed in terms of velocity and depth of the resulting flood.
Nature of floodplain	The depth and velocity of floodwaters will vary with distance from the source of the flooding (breach, river, overtopping, etc.) which, in turn, will depend on the nature of the floodplain (topography, presence of obstructions, etc.). As such, the knowledge of the floodplain will inform the estimates of flood depth and velocity (as opposed to being another variable).

### 5.3 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.

In the absence of a flood, the distributions of people amongst these locations (or probabilities of particular individuals being in a particular location) will vary with nature of the area, time of day, time of year, etc. By way of example, by night in mid-winter in a small town, the vast majority of people would be at home in, predominantly, bedrooms on the first floor. This, of course, would not be the case on a sunny summer Saturday afternoon, when many people would be outdoors in their gardens, in parks and out shopping along the High Street.

Within the UK, the usual precursors to flooding are heavy rainfall and/or storms at sea. Such conditions are likely to reduce the numbers of people outdoors on foot. However, the dominant factor will be the presence of flood warnings and, in extreme cases, evacuation of exposed people. The effectiveness of such emergency plans will depend, to some extent, on the nature of the flooding. At one extreme, the lower stretches of large rivers can receive several days warning of possible flooding allowing for people to be alerted and to take appropriate evasive action. At the other extreme, flooding can occur very quickly - most notably with a failure of a coastal defence - allowing no time for a flood warning. Interestingly, nearly 70% of 655 respondents from 18 locations who were flooded (by rivers) in 2000 (as surveyed in the 'intangibles' study - RPA, 2003) received no flood warning prior to their house being flooded.

## 5.4 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.

## 5.5 Quantifying the relationships (exposure assessment) for a single event

### 5.5.1 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.

A method for evaluation of the overall risks based on an assessment of the full range of floods that could occur is given in Section 5.7.

### 5.5.2 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 - where the degree of hazard is related to depth, velocity and debris. The first step is therefore to define the hazard zones. Hypothetical examples of flood hazard zones are given in this

section. It should be appreciated however that the method can apply to any definition of flood hazard zone, and this is discussed in Section 6.1.

Based on the work considered in Section 4, it is clear that the degree of hazard is a function of both velocity ( $v$ ) and depth ( $d$ ). However, it should be noted that whilst a flood with depth but no velocity is hazardous, a flood with (virtually) no depth is not. For the purposes of this analysis, the degree of hazard will be associated with the function  $(v + 1.5) \times d$ . A further factor for debris is added to reflect the degree of increased hazard. This expression is based on experience of flood hazard estimation. It is recognised that the expression appears rather arbitrary and refinement of this relationship is proposed in Phase 2, based on a more detailed assessment of previous work together with possible new research.

A hypothetical example is presented in Table 5.2.

**Table 5.2 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

### 5.5.3 Determining those exposed

As discussed above (Section 5.3), 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, for this preliminary analysis a simple scoring system (on a three point scale) will be used. There is scope for refinement of this approach in Phase 2 once the basic approach and methodology has been established. Furthermore, at this stage, it is not considered feasible to develop a meaningful expression relating timing of the flood to the numbers of injuries as it has not been determined (from looking at previous events) whether or not the timing is a critical factor.

The scoring system used in this analysis is shown in Table 5.3.

**Table 5.3 Area vulnerability**

Parameter	1 - Low risk area	2 - Medium risk area	3 - High risk area
Flood warning <sup>1</sup>	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 <sup>2</sup>	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: <sup>(1)</sup> In this context, flood warning includes emergency planning, awareness and preparedness of the affected population, and preparing and issuing flood warnings.

<sup>(2)</sup> 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 5.4 for each of the hazard zones.

**Table 5.4 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 5.5. 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 5.5 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

#### 5.5.4 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 5.5) 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 5.6 will be used. The number of parameters and values will be reviewed in Phase 2.

**Table 5.6 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 5.5) 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 5.7 in order to generate values for Y.

The resultant number of injuries is then simply the number of people at risk (from Table 5.5) multiplied by Y as shown in Table 5.8.

**Table 5.7 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	above nat'l average	50		25	75%
100-250	below nat'l average	10	below nat'l average	10	20%
250-500		10	around nat'l average	25	35%
500-1000					

**Table 5.8 Generating numbers of injuries and deaths**

Distance from river /coast (m)	N(ZE) Table 5.5	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 5.8) provides an overall result of a predicted 89 injuries of which 7 are fatalities.

### 5.5.5 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. Given the simplicity of the model, it would be relatively easy to undertake several runs for various flood scenarios each characterised by a likelihood and, for breaches, different locations.

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.

## **5.6 Application of proposed single event methodology to three case studies**

### **5.6.1 Gowdall**

Gowdall is a village in the East Riding of Yorkshire which was extensively flooded (from the River Aire) in autumn 2000 to a depth of about a metre. The estimated annual probability of the flood was 1 in 100. Over one hundred properties were flooded. For simplicity, the whole of the flooded area will be taken as a single hazard zone.

#### **Hazard rating**

Taking a depth of 1.0m, an assumed velocity of 0.5 m/sec and a debris factor of 0 (i.e. debris unlikely) gives a hazard rating (HR) of:  $\{1 \times (0.5 + 1.5)\} + 0 = 2$ .

#### **Area vulnerability**

There was a flood warning (score 2), the speed of onset was very gradual (score 1) and the area is residential (score 2) to give an area vulnerability (AV) score of  $2 + 1 + 2 = 5$ .

#### **Those at risk**

The percentage of those at risk, X, is simply  $HR \times AV = 2 \times 5 = 10\%$ . Taking the flooded population as 250 (for over 100 properties), the population exposed to the risk is then  $10\% \times 250 = 25$ .

#### **People vulnerability**

Based on a site visit (undertaken as part of the 'intangibles' study), the percentages of very old and infirm, etc. are not considered to be significantly different from the national average. On this basis, the value for Y =  $25 + 25 = 50\%$ .

#### **Numbers of injuries and deaths**

The predicted number of injuries is  $25 \times 50\% = 13$ . The associated fatality factor is 4% (based on twice the hazard rating of 2) giving 0.5 fatalities.

#### **Comment**

These findings appear reasonable and are consistent with the findings from the 'intangibles' study (RPA, 2003) in which about a third (36) of the flooded properties were subject to interviews. Although no fatalities were reported in Gowdall, amongst the households interviewed, three direct injuries (i.e. physical injuries due to action of floodwaters) and eight indirect injuries (i.e. physical injuries due to overexertion, etc.) were reported.

### **5.6.2 Norwich**

Norwich suffered extreme flooding in 1912 with, perhaps, 2,500 people flooded. The estimated annual probability of the flood was 1 in 800. For the purposes of this example, two hazard zones are taken. The first with 500 people is close (within, say, 50m) to the main river channel and the second with 2,000 people is for flooded areas slightly further away. These are based on a review of a detailed City Engineer's Report (Collins, 1920) as well as a contemporary illustrated account of the flood (Roberts & Son, 1912).

#### **Hazard rating**

The derivation of the hazard rating is shown in Table 5.9.

**Table 5.9 Hazard rating for Norwich flood, 1912**

Distance from river	N(Z)	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating= $d(v+1.5) + DF$
<50m	500	1.5	1	0	3.75
>50m	2,000	1	0.2	0	1.7

**Area vulnerability**

There was no flood warning (score 3), the speed of onset was very gradual (score 1) and the area is residential (score 2) to give an area vulnerability (AV) score of  $3 + 1 + 2 = 6$ .

**Those at risk**

The percentage of those at risk, X, is simply  $HR \times AV$  and the population exposed to the risk is then  $X \times N(Z)$ . The associated calculations are summarised in Table 5.10.

**Table 5.10 Generating X (% of people at risk) for Norwich, 1912**

Distance from river	N(Z)	Hazard rating (HR)	Area vulnerability (AV)	$X = HR \times AV$	N(ZE)
<50m	500	3.75	6	23%	113
>50m	2,000	1.7	6	10%	204

**People vulnerability**

The percentages of very old and infirm, etc. are not considered to be significantly different from the national average. On this basis, the value for  $Y = 25 + 25 = 50\%$ .

**Numbers of injuries and deaths**

The predicted number of injuries is then simply 50% of the values presented in Table 5.10. The associated fatality factors are 7.5% and 3.4% (based on twice the hazard rating) for the two hazard zones. The results are summarised in Table 5.11.

**Table 5.11 Generating numbers of injuries and deaths for Norwich, 1912**

Distance from river	N(ZE)	$Y = 1 + 2$ (as %)	No. of injuries	Fatality rate = $2 \times HR$	No. of deaths
<50m	113	50%	56	7.5%	4
>50m	204	50%	102	3.4%	4
All			158		8

**Comment**

Once again, these findings appear reasonable and are consistent with the reported four fatalities which actually occurred.

**5.6.3 Lynmouth**

Lynmouth suffered a devastating flood in August 1952 due to very rapid flow down the East and West Lyn rivers. The estimated annual probability of the flood was 1 in 750.

Various articles have been reviewed and for the purposes of this analysis, three hazard zones are taken where these have been based on the numbers of houses destroyed (38), houses severely damaged (55) and houses damaged (72).

### Hazard rating

The derivation of the hazard rating is shown in Table 5.12.

**Table 5.12 Hazard rating for Lynmouth, 1952**

Distance from river	N(Z)	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating= $d(v+1.5) + DF$
very close	100	3	4	2	18.5
close	100	2	3	2	11
nearby	200	1	2	1	4.5

### Area vulnerability

There was no flood warning (score 3), the speed of onset was rapid (score 3) and the area was residential (score 2) to give an area vulnerability (AV) score of  $3 + 3 + 2 = 8$ .

### Those at risk

The percentage of those at risk, X, is simply  $HR \times AV$  and the population exposed to the risk is then  $X \times N(Z)$ . The associated calculations are summarised in Table 5.13.

**Table 5.13 Generating X (% of people at risk) for Lynmouth, 1952**

Distance from river	N(Z)	Hazard rating (HR)	Area vulnerability (AV)	$X = HR \times AV$	N(ZE)
very close	100	18.5	8	100% <sup>1</sup>	100
close	100	11	8	88%	88
nearby	200	4.5	8	36%	72

Notes: <sup>1</sup>Since  $HR \times AV = 148$  which is greater than 100, X has been taken as 100%.

### People vulnerability

The percentages of very old and infirm, etc. are not considered to be significantly different from the national average. On this basis, the value for  $Y = 25 + 25 = 50\%$ .

### Numbers of injuries and deaths

The predicted number of injuries is then simply 50% of the values presented in Table 5.13. The associated fatality factors are 37%, 22% and 9% (based on twice the hazard rating) for the three hazard zones. The results are summarised in Table 5.14.

**Table 5.14 Generating numbers of injuries and deaths for Lynmouth, 1952**

Distance from river	N(ZE) Table 5.13	Y = 1 + 2 (as %)	No. of injuries	Fatality rate = 2 x HR	No. of deaths
very close	100	50%	50	37%	19
close	88	50%	44	22%	10
nearby	72	50%	36	9%	3
All			130		31

**Comment**

Although there are considerable uncertainties as to the precise numbers of people within each of the hazard zones and the associated estimates of depths and velocities, the assumptions made do not appear unreasonable. The resultant prediction of 130 injuries of which 31 were fatal is consistent with the actual death toll of 34.

**5.7 Evaluating the overall risks****5.7.1 Flood risk criteria**

In PPG25 (DTLR, 2001), flood likelihoods have been assigned degrees of tolerability as follows:

- *Little or no risk* - probability of flooding <0.1% per year (i.e. less than 1 in 1,000 per year)
- *Low to medium risk* - probability of flooding 0.1% - 1% per year (i.e. between 1 in 1,000 and 1 in 100 per year) for fluvial flooding and 0.1% - 0.5% per year (i.e. between 1 in 1,000 and 1 in 200 per year) for coastal flooding
- *High risk* - probability of flooding >1% per year (i.e. greater than 1 in 100 per year) for fluvial flooding and >0.5% per year (i.e. greater than 1 in 200 per year) for coastal flooding.

If the risk of drowning is of the order of 1 in 1,000 per major flood event (and there is some evidence to support this based on a review of major UK floods since 1900, JBA (2000)), then it can be seen that the (implied) borderline of intolerable risk for drowning as a result of fluvial flooding is of the order of: 1% per year (flood likelihood) x 0.001 (probability of drowning) = 1 in 100,000 per year.

However, it must be stressed that the ‘risks’ referred to in PPG25 simply relate to flood likelihoods which may or may not result in a significant risk of injury or death as explored further below.

**5.7.2 Risk characterisation**

The method presented in Sections 5.1 to 5.5 provides estimates of death/serious harm to people for single events. The purpose of this analysis is to integrate the results from single events to provide an overall assessment of the annual risk of death/serious harm from flooding.

This final stage of the risk assessment is the risk characterisation which is defined as:

*The quantitative or semi-quantitative estimate, including attendant uncertainties, of the probability of occurrence and severity of adverse effect(s)/event(s) in a given population under defined exposure conditions based on hazard identification, hazard characterisation and exposure assessment.*

Although there is merit in presenting individual risks, it is likely that the methodology will present numbers of injuries for a range of flood events (each of a different scale and likelihood). It is likely that there will need to be some simple conversions to be made in order to determine the equivalent level of individual risk.

This is illustrated by an example, in which the numbers of injuries and fatalities are calculated for three zones (A, B, C) and three flood conditions. In addition, it has been assumed that there is a ‘threshold’ (taken as a 1 in 10 year event) at which nobody is affected. The results are summarised in Table 5.15. A more detailed account is presented in Appendix F including the derivation of the values in Table 5.15 (from Table F.4).

**Table 5.15 Presenting flood risks**

Zone	N people	No of injuries (fatalities) for events with return periods of			Individual Risk <sup>2</sup> of death within each zone by events with return periods of			Individual Risk by Zone
		20 yrs <sup>1</sup>	50 yrs	250 yrs	20 yrs	50 yrs	250 yrs	
A	800	16 (0.2)	40 (0.4)	80 (0.8)	$1.0 \times 10^{-5}$ <sup>3</sup>	$1.1 \times 10^{-5}$	$1.2 \times 10^{-5}$	2.3 to $3.3 \times 10^{-5}$
B	1000	0 (0)	30 (0.3)	70 (0.7)	0	$9 \times 10^{-6}$ <sup>3</sup>	$8 \times 10^{-6}$	0.8 to $1.7 \times 10^{-5}$
C	1200	0 (0)	0 (0)	54 (0.5)	0	0	$7.2 \times 10^{-6}$ <sup>3</sup>	0 to $7.2 \times 10^{-6}$

Notes: 1) The likelihoods of events with return periods of 10, 20, 50 and 250 years are 0.1, 0.05, 0.02 and 0.004 respectively. Note that there are no injuries (nor fatalities) associated with events with return periods up to 10 years.  
 2) For each event, the risk calculation is based on the incremental likelihood (and average numbers of people affected). In other words, the incremental likelihoods for the three flood events considered are: 0.05 (= 0.1 - 0.05); 0.03 (0.05 - 0.02); and 0.016 (= 0.02 - 0.004) respectively.  
 3) The individual risk applies to the average population affected. In these cases the individual risk applies to N/2 people.

For each flood event, the numbers of injuries ( $N_{inj}$ ) and deaths ( $N_{fat}$ ) are estimated by zone. The product of the incremental flood event likelihood,  $df$ , and the (average) number of associated deaths ( $N_{fat}$ ), provides a basis on which to derive the associated contribution to the ‘average’ level of individual risk. This is done by simply dividing the product ( $df \times N_{fat}$ ) by the average number of people within the zone being considered ( $N_{aff}$ ). Summing these contributions over the flood events being considered provides an estimate of the overall level of individual risk within each zone. As illustrated in Appendix F, this will tend to slightly overstate the level of individual risk.

More generally, the sum of all the ( $df \times N_{fat}$ ) products provides a probable loss of life value. Across all three events, this totals  $3.9 \times 10^{-2}$  (statistical) lives lost per year - or,

more simply, an average of 1 death per 26 years. Again this will tend to be a slight overestimate (see Appendix F for more details).

### 5.7.3 Comparing the results with individual risk criteria

As illustrated in Table 5.15 (and as would be expected), the level of individual risk is greatest for Zone A (which is most affected by flooding) and least for Zone C (which is only affected by severe flooding). As such, the overall average individual risk of becoming fatality in both Zones A and B is slightly over our suggested target of 1 in 100,000 ( $= 1 \times 10^{-5}$ ) per year. However, those in Zone C will be at an 'acceptable' risk (i.e. below the suggested target).

Although oversimplified, the average individual risks from the three case studies are presented in Table 5.16. These show that the individual risks at Lynmouth in 1952 and Gowdall in 2000 are above the suggested target level of 1 in 100,000. The risk associated with the 1912 flood in Norwich is below the target level.

**Table 5.16 Presenting flood risks for case studies**

Event	Likelihood (f)	Pop. within area	No. of injuries	N deaths predicted	Deaths per year (fN)	Av. Ind Risk (per year)
Norwich, 1912	1 in 800 per year	2,500	158	8	$1.0 \times 10^{-2}$	$4 \times 10^{-6}$
Lynmouth, 1952	1 in 750 per year	400	130	31	$4.1 \times 10^{-2}$	$1 \times 10^{-4}$
Gowdall, 2000	1 in 100 per year	250	13	0.5	$1.0 \times 10^{-2}$	$4 \times 10^{-5}$

## 5.8 Review of the proposed methodology

The outline methodology described above is based on an interpretation of the key variables that contribute to flood risk. The purpose of this section is to check that all the causes of death/serious injury outlined in Section 2 are (or could be) taken into consideration. The main causes of death/serious injury are summarised in Table 5.17 below, together with the way in which they are taken into account in the methodology.

**Table 5.17 Flood risk factors**

Factor (see Section 2)	How each factor is taken into account in the methodology
Flow velocity	Hazard rating
Depth of flooding	Hazard rating
Speed of flooding	Area vulnerability
Flood warning	Area vulnerability
Extensive floodplains (evacuation difficult)	Area vulnerability (linked to flood warning)

**Table 5.17 Flood risk factors (continued)**

Factor (see Section 2)	How each factor is taken into account in the methodology
Pre-existing health/mobility problems	People vulnerability
Failure and/or overtopping of protective structures including flood defences	Velocity and depth of flooding are included in hazard rating. Lack of warning is included in area vulnerability
Debris	hazard rating
Flood duration	Could be included in hazard rating, but not considered to be a significant factor in UK floods (see Table 5.1).
Building collapse	Area vulnerability, although not considered to be a significant additional factor for UK floods.
Being swept away	Caused by velocity and depth of flooding, and included in the hazard rating.
Exposure	Linked to flood duration (see above)
Pollution	Not specifically included
Trapped in buildings	Area vulnerability
Trapped in vehicles	Could be included in area vulnerability
Falling down manholes, etc	Not specifically included
Previous flood experience and awareness	Could be included in people vulnerability
Timing (day/night)	Not considered feasible at this stage but could be included as an overall 'timing factor' in the final method (for example, deaths/injuries could be assumed to increase by 'x%' for a flood at night in a residential area).

The methodology provides a way of calculating the number of people at risk of injury/death due to flooding (and individual risk) in each hazard zone. It is proposed that the methodology is developed and applied as part of a map-based system in order to calculate flood risks to people. The overall approach is discussed in Section 6.

## **6. CONCEPTUAL APPROACH TO ESTIMATING FLOOD RISKS TO PEOPLE**

The overall approach to estimating flood risks to people is shown on Figure 6.1. This is based on the methodology outlined in Section 5. The proposed methodology for each stage is outlined below together with issues that will have to be considered in Phase 2. The objective is to produce a method which could be applied using a map-based approach in which flood risks to people are calculated spatially for selected areas, for example communities.

### **6.1 Define hazard zone**

The first step will be to define hazard zones. The exact way in which this is done will require further consideration in Phase 2. Options include:

- Assume that each hazard zone corresponds to a particular flood return period. This has the advantage that it could be derived from flood risk maps which have several return periods. Some of these exist already and others are planned. However this approach would not accurately reflect the actual hazard. For example, in a wide flat floodplain, the flood risk areas for all return periods will be very similar but the depth and velocity will vary considerably
- Estimate the boundaries of hazard zones based on the distance from the river/coast. Standard values could be used for locations with different characteristics (e.g. river size, valley slope, floodplain width, etc)
- Assume that each hazard zone corresponds to a range of values of flood hazard rating. This is technically a better approach, but requires the calculation of flood hazard to define each zone.

At this stage it is proposed that the third approach is adopted, and flood hazard zones are based on the flood hazard rating given in Section 5.5.2. The zones will be classified according to the degree of risk. For example, the zones may be classified as ‘very high’, ‘high’, ‘medium’ and ‘low’ risk. ‘Very high’ risk might correspond to a hazard rating value of greater than 10, and ‘high’ risk might correspond to a hazard rating value in the range 7 to 10.

It is proposed that the hazard zones are based on the estimated 100-year flood (fluvial) and 200-year flood (coastal), as flood maps for these return periods are available for the whole country.

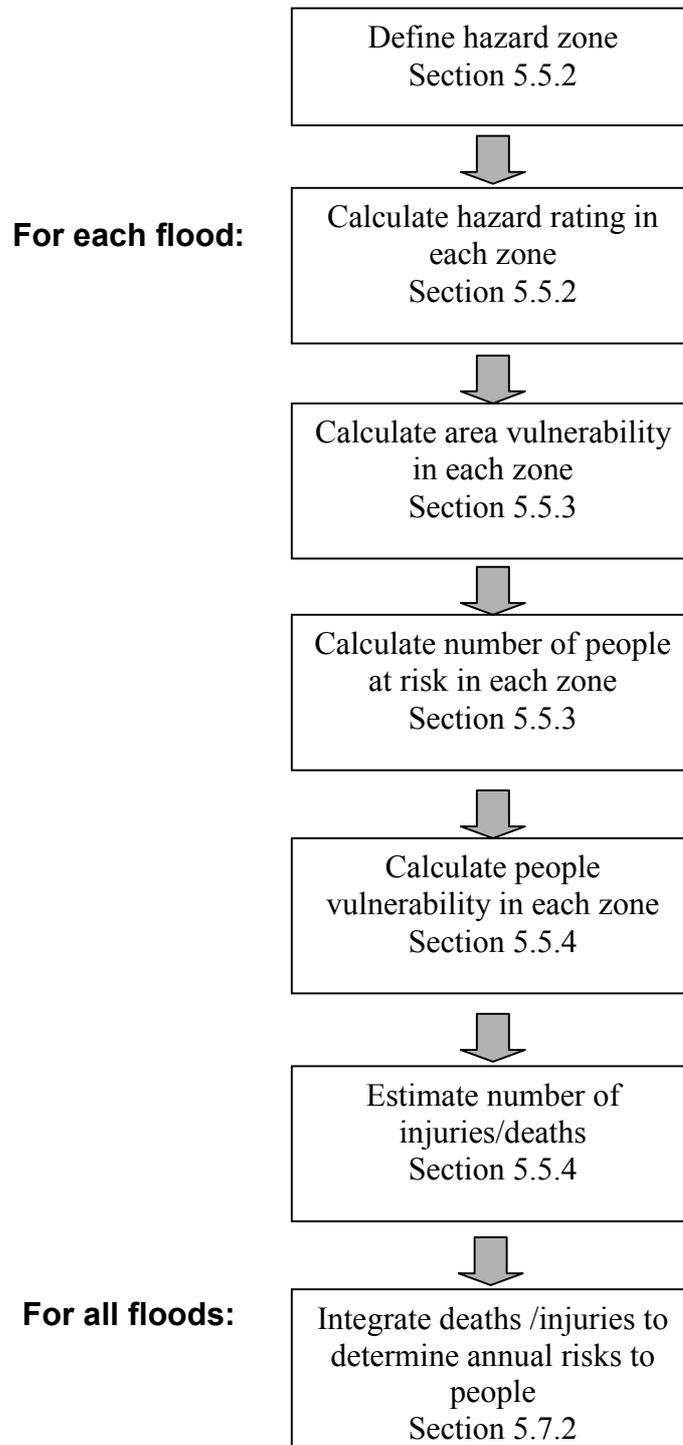
Hazard zones must take account of the proximity of flood defences. In general, areas close to defences should have a high or very high hazard rating. This could be linked to the condition of defences which is being researched under the Risk Assessment for Strategic Planning (RASP) project (Defra/Environment Agency 2003b).

It is also proposed that separate hazard zones are established for seawalls prone to severe wave overtopping.

Thus the hazard rating must be calculated at this stage for the floods specified above, and requires information on:

- Flow velocity
- Flood depth
- Debris potential.

The availability of these data is discussed in Section 7.1.1. The formula for calculating hazard rating will require review to ensure that it provides consistent values of flood hazard. This will be done using existing research results and possibly new research, as discussed in Section 7.2.2.



**Figure 6.1 Overall methodology**

## **6.2 Calculate hazard rating in each hazard zone**

The hazard rating is calculated in order to define hazard zones as described in Section 6.1 using the 100-year flood (fluvial) and the 200-year flood (coastal). It will be necessary to estimate the hazard rating for other floods in order to estimate the annual flood risk. Ideally the hazard zones should not change, but the hazard rating in each zone will change for different floods.

In addition, the way in which the hazard rating is applied in each hazard zone will require further consideration in Phase 2. Options include:

- Use a single average value of hazard rating for each hazard zone. This will not identify variations within the zone, particularly in cases where an area of high area or people vulnerability has a value of hazard rating that differs significantly from the average value
- Sub-divide the hazard zones and calculate a value of hazard rating for each sub-zone. This may be advisable where the area vulnerability and/or population vulnerability vary significantly within the zone.

## **6.3 Calculate area vulnerability in each zone**

The area vulnerability will depend on several factors including:

- Speed of onset of flooding
- The availability of flood warning, and warning time
- Status of flood awareness and emergency planning
- Nature of area including property types, size of floodplains, etc.

It will be necessary to obtain data on all these factors and combine them to produce an area vulnerability score for each flood hazard zone.

## **6.4 Calculate number of people at risk in each zone**

The number of people at risk in each flood hazard zone must be calculated. This could be based on the existing methodology in the Modelling and Decision Support Framework (MDSF). This approach uses population census data for each enumeration district, and spreads the population in proportion to the number of residential properties. An alternative approach would have been to assume a constant population density throughout the district but this could lead to very erroneous estimates of the number of people at risk because floodplains are often less developed than adjacent areas.

## **6.5 Calculate people vulnerability in each zone**

The people vulnerability requires information on:

- Age
- Health, including the number of people with disabilities or sickness.

These data can be obtained from national census data. In the MDSF referred to above, a Social Flood Vulnerability Index (SFVI) has been calculated and mapped

(Defra/Environment Agency 2002). This SFVI is concerned with the overall impacts of flooding, not just the risk of death/injury.

A similar approach could however be adopted for flood risk mapping but using a different way of expressing people vulnerability.

## **6.6 Estimate number of injuries/deaths**

The method for estimating the numbers of injuries/deaths is outlined in Section 5.5.4. Some further work may be required to refine the method although the lack of reliable data on injuries would make any method difficult to calibrate. As indicated in Section 5.6, the relatively simple approach outlined in Section 5 provides reasonable results.

## **6.7 Determine annual risks**

The method must be applied for a number of floods. The results are then plotted against frequency of occurrence, and then integrated in order to estimate the average annual risks. In view of the likely difficulties obtaining data for a range of floods nationally, it may be possible to develop an estimate of annual average risk based on a small number of flood events.

## 7. DATA AND R&D REQUIREMENTS

### 7.1 Data and information requirements

The estimation of flood risk will require a range of data and information, some of which is available already. Data requirements and data availability are discussed in this section. Ideally the intention should be to develop a method that can be applied using existing or planned national data sets in order to avoid the need to collect new data on a national scale. It may however be necessary to collect local data for developing and calibrating methods before they are applied nationally.

#### 7.1.1 Hazard zone definition

In order to define the hazard zone, the following information is required for the 100-year flood (fluvial) and the 200-year flood (coastal):

- Flow velocity
- Flood depth
- Debris potential.

Flood maps for these floods are available for the whole country. It would be possible to produce flood depth grids using the MDSF, which can calculate the depth from the water surface to the ground level as specified in a national Digital Terrain Model (DTM).

One problem with using information from different sources is the question of variations in datum level. For example, if the DTM is accurate to  $\pm 1.0\text{m}$ , it is possible that the whole DTM could be up to 1m high or low compared with the water surface. This will have a large impact on flood depth. If possible, flood outlines should be used that are derived from the same DTM used to calculate flood depth.

Some of the flood mapping methods currently used for national and local flood mapping are capable of providing flow velocity, although the information is not always generated. The availability of velocity information from standard approaches for flood mapping is summarised in Table 7.1.

**Table 7.1 Flood mapping methods: velocity data**

Flood mapping type and method	Availability of velocity data for floodplains
Fluvial Section 105 Survey: IH 130 method	Not available
Fluvial/Coastal Section 105 Survey: Historic flood outlines	Not available
Fluvial/Coastal Section 105 Survey: Flood basin model or projection of maximum levels	Not available
Fluvial/Coastal Section 105 Survey: 1-D hydrodynamic modelling	Velocity profile could be generated along a cross-section

**Table 7.1 Flood mapping methods: velocity data (continued)**

Flood mapping type and method	Availability of velocity data for floodplains
Fluvial/Coastal Section 105 Survey: 2-D hydrodynamic modelling	Velocity vectors can be generated
National Fluvial Extreme Flood Outline using JFLOW	Velocity can be generated but accuracy is unknown
National Coastal Extreme Flood Outline (method not known)	Velocity can be generated from 2-D models that are used for about 70% of the coast but accuracy is unknown. The remainder is based on a projection of maximum levels approach (see above)
National fluvial flood mapping using Normal Depth method	Velocity profile can be generated along a cross-section but less accurate than a 1-D model

Where velocity data are unavailable, it would be necessary to estimate a velocity equivalent. This requires further investigation but suggested methods include:

- An equation of the form  $Velocity = f(\text{depth, slope, roughness})$  in fluvial floodplains
- Empirical equations for velocity where coastal defences fail or are overtopped, based on observations and detailed modelling results. The equation might be of the form  $Velocity = f(\text{defence height, hydraulic head, distance from defence})$
- A hazard rating based on location, as discussed in Section 7.1.2.

For areas which are prone to flooding as a result of flood defence failure, information on the condition of defences may be needed. This should be available for the National Flood and Coastal Defence Database (NFCDD).

Debris potential is a function of land use in the upstream catchment/floodplain. Information on land use would be needed to estimate debris potential.

### **7.1.2 Hazard rating calculation for each zone**

The hazard rating in each zone will vary for different floods. In order to estimate the hazard rating for floods of different return periods, the same depth and velocity data as for the floods referred to in Section 7.1.1 will be needed. However, the amount of data available for floods of other return periods is much less.

In many areas there are no data for floods of other return periods. The Extreme Flood Outline project will provide an estimated 1000-year flood outline. National flood mapping being carried out on behalf of a private company would provide the information required for rivers. In this case a method involving the calculation of normal depth is being applied.

In view of the likely lack of velocity data it may be necessary to derive empirical relationships for different return periods based on the 100-year flood (fluvial) and the

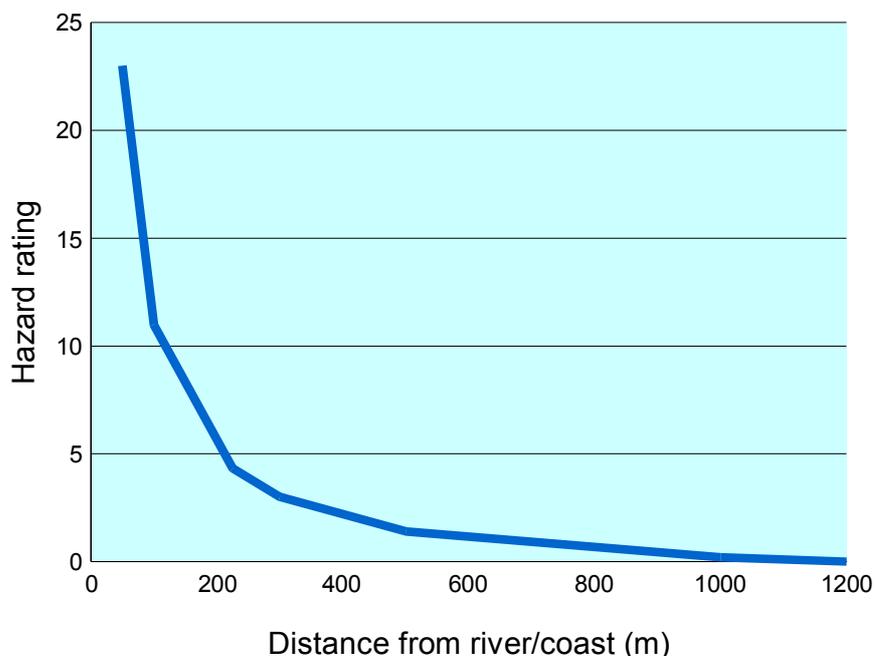
200-year flood (coastal). It may be possible to estimate a hazard rating score based on these floods plus the characteristics of the area at risk, type of flooding (for example coastal or fluvial), the presence of defences and the load (in terms of the depth of water in front of the defences), and the distance from the source of flooding. Further research will be needed (possibly in Phase 2) if it decided to consider this approach in more detail.

In the absence of any data, a first approximation could be made using the simple expression:

$$HR = (D_{max}/D) - 1$$

where: HR = hazard rating at distance D  
 D<sub>max</sub> = extent of flooding from source (m)  
 D = distance from flood source (m)

It will be noted that at D = D<sub>max</sub>, HR = 0 since the flood depth will be zero. An illustrative plot of HR against D is presented in Figure 7.1 for D<sub>max</sub> = 1200m.



**Figure 7.1 Hazard rating against distance (D<sub>max</sub> = 1200m)**

### 7.1.3 Area vulnerability calculation for each zone

Information needed to assess the area vulnerability includes:

- Speed of onset of flooding
- The availability of flood warning, and warning time
- Status of flood awareness and emergency planning
- Nature of floodplain including property types, size of floodplains, etc.

Information on the speed of onset of flooding is patchy, and is linked to the availability of flood warnings and also the status of flood awareness and emergency planning. If

there are no flood warnings, people will still be taken by surprise even if the flood could have been predicted hours in advance.

Generally the Environment Agency try to provide a flood warning for areas where there is 2 hours or more of warning time. Thus flood warning data is likely to be available in three categories:

- Areas that have a flood warning system
- Areas that do not have a flood warning system because the available warning time is too short
- Areas that do not have a flood warning system for other reasons.

It will be important to identify areas where the warning time is less than two hours as these are where flash floods may occur, and people will be particularly prone to death/injury during a flood.

Speed of onset is also affected by whether or not there are flood defences, as failure or overtopping of defences can cause very rapid flooding. Data on flood defences is available from the NFCDD. Ideally a layer showing relevant defences (i.e. raised structures such as embankments, walls and dams) should be obtained. The biggest difficulty with flood defence failure is predicting the probability of failure. The probability is generally low but the potential consequences are high. Information based on methods developed in the RASP project may be needed to estimate flood probability, which includes the probability of defence failure.

The sources of data to be used to describe the nature of the floodplain require consideration during the development of the mapping system. It would be relatively easy to make an allowance for the size of floodplain from an inspection of flood map/hazard zone data. However information on property type may require the use of large and relatively detailed databases.

The MDSF has a database of properties based on the AddressPoint and Focus databases, that includes all residential properties together with all other properties by category (including, for example, campsites). However the data on residential properties does not distinguish between property type. Either another database should be sought, or local knowledge on property type will be needed for high-risk areas.

#### **7.1.4 Number of people at risk in each zone**

Data for population are available in the form of national census data by enumeration district. Enumeration districts will have very different boundaries than flood hazard zones, and it will be necessary to estimate the population in each hazard zone by combining data from each enumeration district. The way in which the population density is estimated will require further consideration in Phase 2. The method adopted by the MDSF is outlined in Section 6.4.

#### **7.1.5 People vulnerability in each zone**

A Social Flood Vulnerability Index (SFVI) was originally developed in the MDSF for Catchment Flood Management Plans. It is a composite additive index based on three social groups (the elderly aged 75 and over, single parents, and the long-term sick) and four financial deprivation indicators (unemployment, overcrowding in households, non-

car ownership, and non-home ownership). All the data were obtained from the 1991 census for enumeration districts as data for the 2001 census were not available. The rationale for the selection of the variables used is given in Table 7.2.

**Table 7.2 Rationale for selection of variables**

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 more likely to be badly affected by floods because they tend to have less income and must cope single-handedly with both children and the flood impacts, and 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.

The choice of data was constrained by the need to (a) use data that is available for the whole of England and Wales and (b) use data that is available for small geographical areas. It was decided to use 1991 census data from the Manchester Information and Associated Services (MIMAS), because this data fits the above criteria, i.e. being available for England and Wales at the level of the enumeration district.

This general approach is considered suitable for estimating people vulnerability, but the variables will change and the scoring will also differ. The key data will include:

- Elderly (Over 75 years of age)
- Pre-existing health problems.

Other data that may be relevant include number of children, presence of ethnic minorities and other data on health (for example, disabled, learning difficulties, etc).

In the absence of reliable local knowledge on the presence of sheltered housing and hospitals, an indication of the general age and health of an area may be derived with reference to National Statistics Online ([www.neighbourhood.statistics.gov.uk](http://www.neighbourhood.statistics.gov.uk)) using a local postcode.

## **7.2 Research needs and further work in Phase 2**

### **7.2.1 General**

There are a number of areas where further research and other work is needed in order to achieve the objectives of the project. These may generally be categorised as follows:

- Scientific research, for example development of a suitable formula for flood hazard
- Development of the methodology, including refinement of the method and calibration
- Development of outputs including a GIS based mapping system.

There are a number of considerations that must be taken into account in the development of the Phase 2 research programme. These include:

- The need to ensure that fluvial, estuarial and tidal flooding is fully covered by the research
- The requirements of specific users of the outputs, particularly the Environment Agency, Defra, emergency planners, emergency services, and those involved in flood defence and land use planning. One particular use of the outputs that has been suggested is to set Byelaw distances (zones adjacent to rivers/coasts where certain activities including development are not permitted)
- The requirements for information at different scales, particular at national, regional (catchment, estuary and coastal cell), strategy and local levels
- The need to link with other ongoing activities, particularly the Agency's Flood Mapping Strategy, research on long-term health impacts of flooding, RASP and the MDSF (for Catchment Flood Management Plans and Shoreline Management Plans).

Recommended work for Phase 2 is discussed in the following sections.

### **7.2.2 Flood hazard rating**

The definition of flood hazard is a crucial element in the whole process. This is the relationship between loss of life/injury and flow velocity, flood depth, debris potential and any other factors that are a direct cause of loss of life/injury during and immediately after floods.

It is recommended that the following research 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 safety or other practical reasons
- Possible consideration of age and gender
- Possibly undertaking experimental work in order to fill gaps in data.

An associated issue that should be considered is the degree of hazard that causes building collapse, and the impacts that this has on people. Specific types of buildings that are particularly prone to collapse during floods include chalets, caravans and other lightweight structures.

One particular area where further research will also be required is how to derive flood hazard data using existing and planned national data sets. For example, if it is not possible to extract flow velocity information, alternative ways of deriving the hazard rating will be needed as discussed in Section 7.1.2. In this case, the research would use the results of detailed studies of floods that include depth and velocity information from

models, and derive methods for calculating hazard rating that do not directly depend on velocity.

### **7.2.3 Area vulnerability**

Area vulnerability is one of the key parameters in the overall method. It includes a number of factors that are to some extent under the control of the Environment Agency, particularly flood warning and speed of onset associated with flood defences. It is recommended that research be carried out on the performance of flood warning (including emergency planning and preparation) specifically in relation to the risk of injury and death. If the results show that the effect is significant and can be included in the area vulnerability score, the results of the project will provide important guidance on the prioritisation and planning of flood warning activities.

It is also recommended that a scoping study is undertaken on the impacts of pollution (other than debris) on the risk of injury/death associated with flood events, as this is an area where very little information exists at present.

### **7.2.4 People vulnerability**

It is recommended that a new 'people vulnerability' Index or parameter is developed of a similar type to the SFVI referred to in Section 7.1.5 but with different variables and scoring. The exact parameters and relationships would be derived in Phase 2, and consideration will be given to such factors as children, ethnic minorities and other health issues in addition to elderly and pre-existing health problems.

Another issue that may justify further research is that of social behaviour during floods including the effects of panic and self-inflicted harm. An example of the latter is the tendency of people to go and look at waves on the seafront during storms. More generally, there are significant numbers of deaths/injuries caused by unwise behaviour that is impossible to predict using the general methods identified in this research.

### **7.2.5 Overall methodology**

Research is needed into the accuracy and refinement of the overall methodology. It is proposed that this is carried out in the following ways:

- Model simulation of a small number of selected events where there is enough information to be able to define within reasonable limits the number and location of people at risk, type of housing, etc. This might include one 'flash' river flood and one coastal flood (or a part of a major flood such as 1953). This will allow the methodology to be refined for the types of events that are most likely to cause risks to people
- Further testing (and refinement) of the methodology using a wider range of case studies to ensure that the results are reasonably reliable in a range of different situations. Particular enhancements that should be considered include a specific factor related to flood warning (see Section 7.2.3 above), the effects of regular flooding on risks to people, and the relationship between injuries and fatalities (currently assumed to be twice the hazard rating). It is recognised that the amount of refinement is likely to be limited by the availability of reliable data
- Development of a procedure for estimating uncertainty and calculating confidence limits for predictions given by the method

- A more precise definition of risk tolerability as this will assist in providing targets for risk reduction by means of flood warning and other measures.

In addition, further work is needed to develop a GIS-based method for implementing the methodology. This will include calculation of the hazard rating, area vulnerability and people vulnerability, and combining these factors to provide an overall estimate of risks to people by hazard zone and community. The method should be suitable for national application.

An intermediate stage would be the development of a functional specification of the required system. An example of such a specification is that used for the MDSF (Defra/Environment Agency 2001).

### **7.2.6 Pilot testing**

The overall methodology and GIS-based implementation should be pilot tested in order to:

- Identify and address problems with the method
- Demonstrate the method
- Provide an estimate of the costs and data requirements for national implementation.

### **7.2.7 Health and Safety Guidance**

In addition to flood risk mapping, the second objective of the project is to provide guidance on the management of flood risks. This could include guidance to Agency staff, emergency planners, emergency services and those affected by flooding. It could include, for example, guidance on when it is not safe to attempt to wade through floodwaters.

### **7.2.8 Summary**

The recommended research and other work for Phase 2 is summarised as follows:

- Research to refine the flood hazard rating formula
- Research to apply the flood hazard rating formula using nationally available data
- Research to assess the impacts of flood warning on risks to people
- A scoping study on the impacts of pollution on risks to people
- Development of the people vulnerability method outlined in Section 5.5.4 using nationally available data
- Research into social behaviour during floods
- Refinement of the overall methodology
- Development of a GIS-based method
- Pilot testing of the method
- Health and Safety guidance.

The above research covers a wide range of topics. It will be necessary to prioritise in order to:

- Develop a complete method within a reasonable budget with associated confidence limits on the results
- Subsequently refine the method based on experience of application.

## 8. CONCLUSIONS OF PHASE 1

- 8.1 The causes of death and serious injury due to flooding have been identified from a literature review. The main factors include flood characteristics (flow velocity and flow depth, location characteristics (size of floodplain, location on floodplain, ‘suddenness’ of flooding and amount of flood warning, type of accommodation, etc) and population characteristics (social vulnerability, behaviour etc).
- 8.2 An approach to risk assessment is proposed which takes account of the likelihood of a flood, the probability that people will be exposed to it and the probability that those exposed to a flood will be killed or injured.
- 8.3 It is proposed that the flood risk is presented in societal terms (i.e. the estimated number of deaths per year caused by flooding in a unit of land, for example a flood cell) and in individual terms (i.e. the annual probability that an individual in a unit of land will die as a result of flooding).
- 8.4 An outline method is proposed for estimating the number of deaths/injuries based on determination of a hazard rating for different ‘hazard zones’ of the floodplain, the area vulnerability (in terms of speed of flooding, flood warning, type of floodplain, etc), the population at risk and the population vulnerability. The methodology has been applied successfully to three case study floods (Norwich 1912, Lynmouth 1952 and Gowdall 2000).
- 8.5 The recommended R&D and other work required in Phase 2 in order to develop and implement the method includes:
- Research to refine the flood hazard rating formula
  - Research to apply the flood hazard rating formula using nationally available data
  - Research to assess the impacts of flood warning on risks to people
  - A scoping study on the impacts of pollution on risks to people
  - Development of the people vulnerability method outlined in Section 5.5.4 using nationally available data
  - Research into social behaviour during floods
  - Refinement of the overall methodology
  - Development of a GIS-based method
  - Pilot testing of the method
  - Health and Safety guidance.

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# APPENDICES



# Appendix A

## Part Form CSG 7 (Terms of Reference)

### SECTION TWO – SCIENCE

**DEFRA funds research in support of its policy requirements. These are described in the DEFRA R & D Strategies, and individual programme objectives may be described in more details in ROAME A's or in documentation supporting advertised calls for proposals.**

8. **Purpose.** Summarise the scientific or technical problem which you propose to address and give reasons why DEFRA support should be given. **This table will expand to accommodate the information you wish to enter. To move to the next field, press the DOWN arrow TWICE.**

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 will identify in outline the relationships between causal factors and the impacts on people. The R&D needed to refine these relationships and develop an appropriate method for flood risk mapping will be carried out in Phase 2.

9. **Scientific context.** Please describe how your proposal relates to the current state of knowledge (full reference, see Annex B) and in which ways the results will advance scientific/technical understanding. **To move to the next field, press the DOWN arrow TWICE.**

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 and velocity or the load. These characteristics vary according to several factors such as geo-morphology, hydrogeology 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" & "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 an overall framework for assessing conditions where serious harm to people could occur, and advise specifically on the conditions which lead to loss of life.

In relation to loss of life, there are numerous large-scale flood events which can provide background data on the key variables. The most severe (in terms of people killed) flood events in Europe in the past 50 years are summarised (chronologically) below:

- 01/02/1953: North Sea flood, Northern Europe - 2,100 killed  
Storm surge in the North Sea. English, Dutch and Belgian coastlines flooded. Some coastal districts under 10 metres of water
- 1959: Ribadelago, Spain - 144 killed  
Structural failure of dam

12/04/1959: Frejus, France - 420 killed	Geological/foundation weakness of dam. Dam collapsed and water washed away part of town
17/02/1962: Floods in Germany, North Sea Coast - 340 killed	Hamburg and western coastal areas affected. High tide and strong wind conditions led to failure of the levee system
27/09/1962: Floods in Barcelona - 445 killed	Flash floods causing damage worth \$34 million. Exact number dead unknown, could be up to 700. Many victims were immigrants living in shanty dwellings or caravans next to, or on the dry river beds
09/10/1963: Vaiont, NE Italy - 2,000 killed	Heavy rain caused landslide, displacing 50% of reservoir water. Overtopping of dam. Caused 70 metre tsunami-like wave destroying villages
3-4/11/1966: Floods in Southern Europe - 113 killed	Heavy rain affected Italy, Switzerland and Austria
26/11/1967: Floods in Lisbon area - 464 killed	Heavy rain in basin of Tejo river caused flash floods
1970: Central Romania – 160 killed	Largest and most destructive floods in Romania's history
18/10/1973: Murcia-Granada-Almeria, Spain - 350-500 killed	Estimates of number of deaths vary
July/August 1997: Northern Europe - 91 killed	Heavy rain leads to major rivers flooding, particularly in Poland and the Czech Republic
July/August 2002: Northern Europe - 100 killed	Heavy rain leads to major rivers flooding, particularly in the Czech Republic and Germany
<i>Sources: Various including: <b>Earthnet</b> website <a href="http://earth.esa.int">http://earth.esa.int</a> and <b>Centre for Research on Epidemiology of Disasters</b> <a href="http://cred.be">http://cred.be</a></i>	

10. **Objective(s).** Please give details of (a) each scientific objective, (b) to what extent these objective(s) are interdependent; and (c) whether any factors exist to delay achievement of the objective(s). Where there is more than one contractor, please show clearly below the roles of each.

(a) **Scientific objective(s).** (Technical and Scientific aims of the research which must be measurable and timebound, please number the objectives). **If your application is accepted, these Scientific objectives will be included in the agreement between you and the Department. Please, therefore, restrict your entry to the salient points and set these out clearly and concisely.**  
**To move to the next field, press the DOWN arrow TWICE.**

1. To identify the circumstances which lead to loss of life or serious harm to people as a result of flooding.
2. To identify relationships between causal factors (including flood hazard) and loss of life or serious harm to people, based on existing knowledge.
3. To provide a context of risk criteria (both individual and societal) for establishing appropriate criteria for flood risks
4. To advise on the R&D needed to refine the relationships referred to in Objective 2 above, a methodology for mapping of flood risks to people based on these relationships, and the way in which the required flood hazard data should be obtained.

It is proposed that the R&D referred to in Objective 4 above will be carried out under Phase 2 of this project.

(b) **Interdependence of objective(s).** To what extent does the success of one scientific objective depend on the successful completion of another? **How essential is each scientific objective in achieving the overall objective. move to the next field, press the DOWN arrow TWICE.**

The successful completion of all four scientific objectives is essential to achieve the overall objective of understanding the relationship between causal factors (including flood hazard) and loss of life/serious harm to people. This in turn is needed for Phase 2 of the project, which is intended to achieve the overall purpose.

(c) **Please give details of any particular factors which might cause delays in the achievement of these objective(s).** What are the chances of this happening; what are the probable consequences; and what steps will you take to prevent this happening? **To move to the next field, press the DOWN arrow TWICE.**

The degree to which the objectives are achieved depends more on the quality of existing information rather than on the ability to access the information. As such, there should be no delays during Phase 1 - once

initiated.

11. (a) **Approaches and Research Plan.** Outline the experimental approaches to be used in realising the scientific objectives and set out the work plan for the life of the project stating clearly how you intend to proceed. Please number the Approaches in the same way as the Objectives. Where there is more than one contractor, please show clearly below the roles of each. **If your application is accepted, the Approaches and Research Plan will be included in the agreement between you and the Department. Please therefore, restrict your entry to the salient points and set these out clearly and concisely. To move to the next field, press the DOWN arrow TWICE.**

1. A literature review will be carried out which will cover the national and international academic literature, news reports, and other information concerning loss of life or serious harm to people caused either directly or indirectly by fluvial and tidal flooding.
2. The risk to people will vary according to flood hazard (flow velocity, depth, duration, warning time, rate of rise), weather conditions during the flood, different age and socio-economic grouping, cultural background, housing type and accessibility to flood warning. There are studies which have evidence of this and these will be included in the literature review. Information from the recent severe flooding in Europe will also be reviewed.
3. The literature review will cover the UK and Europe and is intended to cover the period 1950 to date. A review of risk approaches will also be carried out to assist with the development of a suitable methodology for assessing risks to people.
4. Factors leading to risks to people will be identified together with corresponding scenarios, including:
  - Scenarios with a high correlation between hazard and risk, for example dam break, flooding of caravan sites behind flood defences, intense rainfall over urban areas, etc.
  - Scenarios with a lower correlation between hazard and risk, for example the Autumn 2000 floods where loss of life resulted from "random" occurrences.
5. The review will also be used to identify information on relationships between hazard and risk. Particular aspects of flood hazard to be investigated will include flow velocity, flood depth, rapidity of flooding and warning time. Contributory factors to flood hazard will also be considered, including the condition of flood defences and likelihood of failure, together with other causal factors including social and physical aspects. Previous work (from the UK and elsewhere) on the formulation of flood risk as a function of these key variables will be reviewed.
6. A review will be carried out of current risk criteria (with a UK emphasis) to provide a (preliminary) basis on which particular levels of flood risk (both individual and societal) may be judged to be of sufficient concern for the areas in which they occur to be identified as 'hot-spots'. This review will consider criteria used in relation to flooding (as currently used in PPG25 for example) and in other fields (such as hazardous installations).
7. A number of simple case study examples will be undertaken for different typical locations in the country (for example, lowland, upland, small catchment liable to flash flooding). The factors which could lead to harm to people will be reviewed in order to try to develop some prototypical algorithms for linking the causal factors to risks to people. Historic information on floods which led to actual harm to people will also be reviewed in order to try to identify the links between causal factors and the impacts on people.
8. The output from Step 7 above will be relationships between risks to people and the magnitude/combination of the causal factors, in order to demonstrate the likely form of such relationships. The relationships will be refined in Phase 2, as discussed below. A framework will also be developed for linking risks to people with frequency of occurrence, leading to an approach (or approaches) to mapping flood risk.
9. The status and availability of flood hazard data will be reviewed in order to identify data requirements and methodologies for collection.
10. The purpose of Phase 2 will be to develop a methodology for mapping of flood risks to people, and approaches to data collection. The research needs for Phase 2 will be specified as part of the Phase 1 project. These are likely to include:
  - Refinement and calibration of the prototypical algorithms between causal factors (including flood hazard, etc) and risks to people.
  - Collection methods and procedures for flood hazard and other relevant data.
  - Case studies to trial the approach
  - Impacts of future changes including climate change



## Appendix B

### Flood hazard assessment for flood emergency planning

(Abstracted from Appendix C of ‘Defra/Environment Agency (2003): **Guide to the Management of Floodplains to reduce Flood Risks**, Report SR 599, HR Wallingford Ltd, February 2003’)

Flood hazard varies both in time and place across the floodplain. Floodwaters flow swift and deep at some locations but in other places they are shallow and slow moving. The variation of hazard and flood behaviour across the floodplain needs to be understood by flood-prone communities, floodplain managers and flood emergency staff.

This Appendix describes flood hazard and gives guidance on how flood hazard can be assessed for different parts of the floodplain.

#### **B.1 Factors affecting flood hazard**

Factors that affect the hazard and disruption caused by a flood can be grouped into the four broad categories:

- Flood behaviour (including severity of flood, response time, rate of rise, depth, flow velocity, duration, water quality)
- Evacuation issues (including evacuation routes and time for evacuation)
- Population at risk (including number and vulnerability of people, flood awareness)
- Emergency management (including flood forecasting, flood warning, flood response, evacuation and recovery).

#### **B.2 Flood behaviour**

##### **B.2.1 Flood severity**

The severity or size of a flood is generally the principal determinant of hazard. Not only does it affect aspects of flooding behaviour that individually influence hazard (e.g. depths, velocities, rates of rise), it also determines the number of people at risk. It is impossible to predict when flooding will occur or the size of the flood. Furthermore there is no guarantee that, if a severe flood has occurred recently, another perhaps larger flood will not occur in the near future.

##### **B.2.2 Response time**

The speed with which a flood occurs following heavy rainfall is also a major contributory factor to hazard, and is sometimes referred to as the “response time” for a particular river catchment. In large river catchments the response time is relatively slow and the available warning time is relatively long. In small steep catchments, the response time is very short and there is often very little available warning time.

On the coasts the it is possible to predict tidal surges many hours in advance, permitting warnings of possible flooding to be issued. However if a defence fails the time taken for flooding to occur can be very quick thus creating a very high level of hazard. In addition, coastal flooding often occurs during very bad weather conditions over the flood risk area, exacerbating the hazard. Coastal flooding generally occurs at high tide,

and therefore flood-prone communities will have some knowledge of when flooding might occur and can be warned of this in advance.

### **B.2.3 Rate of rise of floodwater**

Situations where floodwaters rise rapidly are potentially far more dangerous than situations where flood levels increase slowly. Typically, the rate of rise of floodwaters is more rapid in small, steep catchments and/or small urban catchments than in their larger, flatter counterparts. It is also rapid in situations where defences fail or are overtopped.

### **B.2.4 Floodwater depth and velocity**

The threat to life and structural damage caused by floods depends largely upon the velocity of flow and depth of floodwaters. These, in turn, depend upon both the size of the flood and the hydraulic characteristics of the river or coast and its floodplain.

The following guidance is given to indicate the type of information needed in a flood hazard assessment:

- Wading by able-bodied adults becomes difficult and dangerous when the depth of still water exceeds 1.2 m, when the velocity of shallow water exceeds 0.8 m/s, and for various combinations of depth and velocity between these limits.
- In assessing the safety of wading, factors other than depth and velocity need to be taken into account such as evenness of the ground surface or presence of depressions, potholes, fences or major stormwater drains.
- Small, light, low motor vehicles crossing rapidly flowing causeways can become unstable when water depths exceed 0.3 m. Evacuation by larger, higher cars is generally only possible and safe when water depths are less than 0.4 m. Large emergency vehicles, for example fire engines, may operate in depths of up to one metre.
- As the depth of floodwater increases, caravans and buildings of light construction will begin to float. In these circumstances the buildings can be severely damaged when they settle unevenly in receding floodwaters. If the flood velocity is significant, buildings can be destroyed and cars and caravans can be swept away. In certain areas, the build up of debris and the impact of floating objects can cause significant structural damage to buildings and bridges.
- The build up of debris can in turn block bridges, culverts and other flood flow routes, thereby increasing flood levels and flood damage.
- At velocities in excess of 2 m/s, the stability of foundations and poles can be affected by scour. As grass and earth surfaces begin to erode, scour holes can develop.
- At depths in excess of 2 m, lightly framed buildings can be damaged by water pressure, flotation and debris impact, even at low velocities. Where buildings are “floodproofed”, and there is a higher level of water outside than inside, the maximum differential pressure that brickwork walls can resist is of the order of one metre.

### **B.2.5 Duration of flooding**

The duration of flooding or length of time a community, town or single dwelling (e.g. farm house) is cut off by floodwaters can have a significant effect on the costs and disruption associated with flooding. In the UK, rescues from isolated properties are generally relatively rapid, but the stress of having to leave a flooded property for a long

period adds significantly to the overall trauma of flooding. The duration of flooding also has a significant impact on damage. The longer the duration the more severe the damage can become and the greater the length of the recovery and repair period.

The duration of flooding on rivers generally correlates with the rate of rise of floodwater, typically being longer for slow rates of rise (larger, flatter catchments) and shorter for rapid rates of rise (smaller, steeper catchments). On the coasts the duration of flooding is to some extent influenced by the tide but in many cases depends on the time it takes to remove floodwater from the affected areas.

### **B.2.6 Floodwater quality**

The temperature of floodwater contributes to the overall hazard. Floodwater is generally cold and in winter can be close to freezing, presenting a significant additional hazard.

In addition, floodwater is often of relatively poor quality. It may be polluted by sewage from foul sewers (particularly during floods caused by urban drainage overflows), oil or chemicals from flooded industrial plants, and any number of other pollutants washed off the floodplains. Sediment is deposited where velocities are low, particularly inside properties, and is often polluted.

Not only does pollution add to the misery of flooding, it also increases damage and adds to the amount of effort needed for post-flood clean up and recovery.

### **B.2.7 Use of models to estimate flood hazard**

Model studies carried out for both flood mapping and flood management predict flood water levels and flood extent. Information needed for the assessment of flood hazard is generally not needed for these studies and is therefore not a standard output. However, the model results can be used for flood hazard estimation in the following ways:

- Flood response (and associated warning) time on rivers is best estimated from time of travel of flood hydrographs between gauging sites. Where gauging sites do not exist, models can be used to estimate warning times by correlating the timing of rainfall or flows at particular locations with the predicted time of flooding.
- Flood response times on coasts are more difficult to predict because of uncertainty over the locations where defences will overtop or breach, and model results may be of little assistance in flood warning.
- Rate of rise of floodwater can be estimated using level hydrographs from models for different locations on the floodplains.
- Depth of flooding for different probabilities of flooding can be obtained directly from model results by comparing flood water levels and ground levels. The Modelling and Decision Support Framework for catchment flood management planning (DEFRA/Environment Agency 2002) provides this information directly for individual properties.
- The average flow velocity at each model section is calculated by the model, and this will give an indication of floodplain flow velocities. Ideally the cross sections should identify flood flow paths in some detail (ie individual streets) to obtain a true estimate of the hazard.
- Flood duration can be estimated from model output hydrographs for floodplain cells.

## **B.3 Evacuation**

### **B.3.1 Evacuation problems**

The levels of damage and disruption caused by a flood are influenced by the difficulty of evacuating flood-affected people and property. Evacuation may be difficult because of:

- The number of people requiring assistance
- The depth and velocity of floodwaters
- Wading problems, which can be exacerbated by, for example, uneven ground, fences, debris and localised high velocities.
- Distance to flood-free ground
- Loss of trafficability on evacuation routes because of rising floodwaters
- Bottlenecks on evacuation routes (i.e. roads cannot cope with the increased volume of traffic and the number of people that have to be evacuated)
- Unavailability of suitable evacuation equipment such as boats, lorries and helicopters.

### **B.3.2 Effective flood access**

The availability of effective access routes from flood-prone areas and developments can directly influence the resulting hazard when a flood occurs.

“Effective access” means a high-level exit route that remains trafficable for sufficient time to evacuate the population at risk (i.e. evacuation can be undertaken solely by motor vehicle). In some urban situations, access to flood-prone residents can be lost relatively early in the flood, for example where:

- Evacuation routes lead downhill onto and across the floodplain. Access to the evacuation route and trafficability can be lost early in the flood because of rising floodwaters
- Cul de sac residential developments built on rising land that only have downhill road access. Vehicular access is likely to be lost early in the flood although it may be possible to evacuate residents by walking to high land behind the development.
- Roadways may become overland flow paths for severe stormwater flooding. This will reduce their trafficability and could affect evacuation.

Thus there is considerable benefit to be gained from taking possible evacuation needs into account in designing regional and local road networks for flood-prone areas.

Access is generally divided into two categories: pedestrian and vehicular. The provision of road access trafficable in all conditions will obviously assist in reducing the flood hazard and enhance the effectiveness of the emergency response.

The suitability of access routes needs to be investigated for a range of flood events. Arrangements and evacuation routes which are suitable for flood events up to a specified standard may become unsafe or inoperable for more severe floods. In potentially hazardous situations, pedestrian access routes at least should be provided which can be used in extreme flood events. Without such access, the danger to the entrapped and their rescuers may be unacceptable.

A potentially hazardous situation develops when rising floodwaters isolate an area of land, leaving an island in a sea of floodwater. The degree of hazard depends on the

depth, velocity and rate of rise of floodwaters between the island and possible places of refuge. Vehicle access may be cut rapidly. Rescue by boat, helicopter or large vehicle may be necessary, so putting the rescuers' lives at risk. Although such a situation may not develop for "normal" floods, a check should be made to see whether rare flood events cause islands to develop, or even worse, to subsequently be submerged.

#### **B.4 Population at risk**

The degree of hazard and social disruption varies with the size of the population at risk. The larger the population at risk, the greater the effort that will be needed for evacuation.

##### **B.4.1 Flood awareness**

A flood aware population is more likely to be effective in evacuating itself and protecting possessions. Flood awareness is largely related to past experience of flooding and greatly influences the time taken by flood-affected people to respond effectively to flood warnings. In communities with a high degree of flood awareness, the response to flood warnings can be relatively prompt, efficient and effective.

The promotion of flood awareness by public education campaigns is an essential component of flood emergency planning.

##### **B.4.2 Warning time**

Flood hazard can be reduced by evacuation if adequate time is available. However, even if people and possessions are fully evacuated, a flood will still cause significant damage and substantial community disruption.

The available flood warning time is linked to catchment response time on rivers, and the timing of high tides where severe conditions are predicted on coasts. In large catchments, flood warnings can be based on rates of rise and peak water levels at upstream gauges. In smaller, more responsive catchments, flood warnings need to be based on rainfall measurements. In the smallest catchments, warnings need to be made on predictions of likely rainfall made before the rainfall occurs, based on weather radar and meteorological forecasting models.

The effective warning time, or actual time available for evacuation and other emergency response activities, is always less than the available warning time. This is because of the time needed to alert people to the imminence of flooding and the time needed to come to terms with this information and take the necessary action. Warnings are issued by a variety of means including Automatic Voice Messaging, the media, loud-hailer and word-of-mouth, particularly by flood wardens.

#### **B.5 Land use**

Land use also influences hazard. There are considerably greater difficulties in evacuating a hospital or a retirement home than an industrial area. Conversely, the flooding of industrial areas might result in the escape of toxic industrial products.

##### **B.5.1 Historic areas**

There are a number of particular problems associated with flooding of historic urban areas. These include:

- Old arch bridges which constrict the flood flow, raising upstream water levels. These are also prone to blockage by debris, further raising water levels
- A legacy of old drainage infrastructure which is liable to blockage
- The dense pattern of building coverage and narrow streets and alleyways, which significantly increase flood levels and velocities
- The high cost of damage associated with old buildings
- The need for careful drying out and restoration, which can take much longer than for modern buildings.

### **B.6 Degree of hazard**

The degree of hazard varies across the floodplain in response to the above factors. As part of the floodplain management process, it is necessary to determine hazard. This is of considerable significance to the appropriateness or otherwise of various land uses.

This document recognises four degrees of hazard.

**Low:** There are no significant evacuation problems. If necessary, children and elderly people could wade to safety with little difficulty; maximum flood depths and velocities along evacuation routes are low; evacuation distances are short. Evacuation is possible using cars. There is ample time for flood forecasting, flood warning and evacuation; evacuation routes remain trafficable for at least twice as long as the time required for evacuation.

**Medium:** Fit adults can wade to safety, but children and the elderly may have difficulty; evacuation routes are longer; maximum flood depths and velocities are greater. Evacuation by cars is only possible in the early stages of flooding, after which 4WD vehicles or lorries are required. Evacuation routes remain trafficable for at least 1.5 times as long as the necessary evacuation time.

**High:** Fit adults have difficulty in wading to safety; wading evacuation routes are longer again; maximum flood depths and velocities are greater (up to 1.0 m and 1.5 m/s respectively). Motor vehicle evacuation is possible only by 4WD vehicles or trucks and only in the early stages of flooding. Boats or helicopters may be required. Evacuation routes remain trafficable only up to the minimum evacuation time.

**Extreme:** Boats or helicopters are required for evacuation; wading is not an option because of the rate of rise and depth and velocity of floodwaters. Maximum flood depths and velocities are over 1.0 m and over 1.5 m/s respectively.

### **B.7 Estimation of hazard**

An appropriate procedure for estimating flood hazard needs to involve an assessment of all the components summarised in Section C.2. The two principal factors that affect the safety and stability of pedestrians wading through floodwaters and motor vehicles traversing flooded roads are the depth and velocity of the floodwaters.

Pedestrians can be swept away by sliding due to a loss of grip between their shoes and the roadway or by falling over under the pressure of floodwater. Motor vehicles are swept away because of loss of friction between their tyres and the roadway caused by flotation, or the pressure of floodwater.

Whilst some work on stability estimation procedures are available, there is currently no definitive guide to the combinations of depth and velocity that cause loss of stability. A comprehensive testing program of people, vehicles and structures is needed before definitive design guidelines can be presented. Any study on the effects on people needs to consider not only the physical issues of flooding but also the psychological effects.

### **B.7.1 Hazard graphs**

The emergency services should undertake hazard analyses as part of the preparation of a flood emergency plan. This requires results from a flood study and an assessment of all factors affecting hazard, such as flood behaviour, flood awareness and possible evacuation problems. Even a relatively crude analysis will identify the main hazards to consider in a flood emergency, and will provide valuable guidance on the deployment of emergency vehicles, etc.

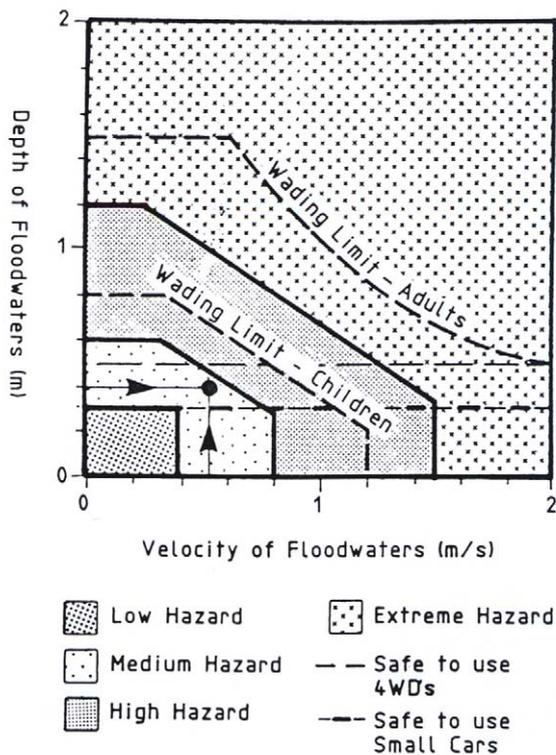
Figures B.1 and B.2 provide a simple graphical means of making a preliminary estimate of hazard along proposed evacuation routes based on the depth and velocity of floodwaters (Fig. B.1) and on the relative evacuation time (Fig. B.2). The following points should be noted:

- The four degrees of hazard shown on Figure B.1 correspond to the hazard descriptions of Section B.6. Also shown on Figure B.1 are depth and velocity combinations for small, low motor vehicles and 4WD (4 wheel drive) vehicles. These are based on Keller & Mitsch (1993) and are used here for demonstration purposes only
- “Relative evacuation time” is the ratio of the time available for evacuation (as determined by flood behaviour and topography) to the minimum time required for orderly evacuation, which depends largely on the number and age of people involved. The time available for evacuation is measured from when the order to evacuate is given until evacuation routes become untrafficable because of rising floodwaters. Thus, a relative evacuation time of 1.0 means that the available evacuation time (as determined by flood behaviour) just balances the required time for evacuation. A relative evacuation time of less than 1.0 means that not enough time is available for an orderly and controlled evacuation.

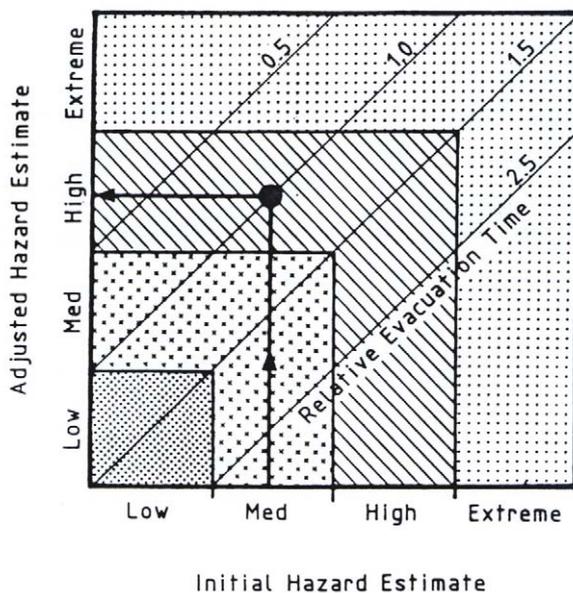
To use Figure B.2, from the “Initial hazard estimate” axis draw a vertical line to the appropriate isoline of relative evacuation time. The “adjusted hazard estimate” is given by the hazard region where the end of the line falls. This procedure does not allow an initial hazard estimate to be reduced in severity. For example, consider the degree of hazard associated with wading through water 0.3 m deep and flowing at 0.5 m/s. According to Figure B.1, the degree of hazard is medium (i.e. fit adults can wade to safety over distances of up to say 200 m, but children and the elderly will have difficulty). If the relative evacuation time is unity (1.0), then according to Figure B.2, the initial estimate of hazard (medium) should be upgraded to high.

### **B.8 Hazard maps**

Mapping of flood hazards will assist in the preparation of flood emergency plans. In preparing such maps, hazard zones should be defined in broad terms which are consistent with the detail of data used to estimate the hazard. Any excessively detailed variation of hazard should be “smoothed” out.



**Figure B.1 Estimation of hazard along evacuation routes**



**Figure B.2 Effect of relative evacuation time on hazard rating.**

Note: the adjusted hazard assessment is not to be a lower hazard than the original assessment

Courtesy: Floodplain Management in Australia: Best Practice Principles and Guidelines. SCARM Report 73, CSIRO Publishing, 2000.

## Appendix C

### Risks to life and serious acute health impacts from floods: Evidence from the research literature

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#### C.1 Introduction

In relation to other natural hazards, floods are high probability events, since protection is not usually provided to reduce the risk to less than 1 in 200 years (0.005 annual probability), and in most countries the standard of protection is considerably lower. However, the risk of death should a flood occur is usually low compared to other hazards, although this depends on the floodplain zone affected.

Nevertheless, floods do kill and sometimes kill hundreds of people (floods in Eastern Mexico in October 1999 resulted in at least 300 deaths ([Independent, October 12, 1999](#))), and where very large areas of low lying land are affected, with very large populations, large numbers of people may die, as in the Bangladesh floods of 1987 and 1988. Very often in major events the number of lives lost may never be accurately known. However, Jonkman *et al.*, (2002) suggest that the death toll for floods in the year 2000 was about 6,000 world-wide, making floods the dominant cause of loss of life from natural hazards, at least in that year.

The flood conditions in which the risks of death are likely to be greatest are those where one or more of the following conditions exist:

- Flow velocities are high;
- Flood onset is sudden as in flash floods, for example the Big Thompson flood, USA, in 1976 and flash floods in Southeast China in 1996 ([Gruntfest, 1997](#));
- Flood waters are deep;
- Natural or artificial protective structures fail by overtopping or collapse. Flood alleviation and other artificial structures themselves involve a risk to life because of the possibility of failure, for example dam or dike failure; and
- Where extensive low lying densely populated areas are affected, as in Bangladesh.

It should be stressed is that where there is a risk of flooding, it is commonly very high relative to that from other hazards. Outside of the Netherlands and some other countries, it is unusual for a flood alleviation project to be designed to protect against a flood more severe with than that with a return period of 200 years.

Consequently, the risk to life from flooding is likely to be higher than those levels of risk which are deemed to be acceptable or tolerable in regard to such hazards as nuclear power stations or chemical plants. For those other hazards, a general rule of thumb has been adopted that an individual risk of death per year of one in one million is a threshold value.

Thus, to be consistent with this threshold value, the conditional risk of death should a flood occur cannot exceed one in ten thousand: there is no doubt that in some contexts the conditional risk of death is considerably greater than this. It is, therefore, essential to assess whether the risk of death is particularly high in any area under study and to determine what are the most appropriate measures to reduce it. These measures may include one or all of the following: emergency plans, flood warnings, the provision of flood refuges or evacuation plans.

Some analyses have been undertaken of past floods (DeKay and McClelland 1993; Kraak 1994) in order to try to estimate the risk of life from flooding but it is difficult in such studies to separate out the small part of the population who were exposed to a high risk from those who were exposed to a much lower risk. Graham's (1999) analysis gives conditional probabilities of death that range from 0.0002 for low severity floods in areas where there is a good understanding of floods and more than sixty minutes of warning to 0.75 in areas just downstream of a catastrophic dam failure occurring without any effective warning.

Research literature on floods (Bennet, 1970; Drescher and Abueg 1995; Green *et al.*, 1985; Handmer and Smith 1983; Heurta and Horton, 1978; Penning-Rowsell *et al.*, 1992; Powell and Penick, 1983; Tapsell *et al.*, 1999; Waelde, Koopman and Spiegel 1998) and on dam bursts (Baum *et al.*, 1983) indicates that these events can have significant health effects, ranging from premature death, higher than expected cancer rates - although the evidence on this is inconclusive - and other clinical problems requiring hospitalisation and medical consultations.

However, a major cause of subsequent health damage seems to be the stress of the flood itself. There is evidence that stress induces immunological changes. Recent qualitative research (Tapsell *et al.*, 1999) suggests that the stress of the flood event itself, the stress and disruption to life during the recovery period and worry about future flooding can have a serious effect on physical and psychological health, as well as the well being, of flood victims. Pre-existing medical conditions were perceived to be exacerbated and some new mental and physical conditions were attributed to the flood event (Tapsell *et al.*, 1999).

## **C.2 The risk to life**

### **Introduction**

Loss of life models in relation to floods have been reviewed recently and comprehensively by Jonkman *et al.*, 2002, who show (as have others) that deaths occur in flood events through a range of circumstances:

- Death rates in floods are high where buildings fail to provide a safe refuge, collapsing or being swept away (Green, Parker and Emery 1983). Timber framed buildings, mobile homes, informal, temporary and fragile structures and tented dwellings may give rise to significant loss of life or hazardous rescues. In many countries, floodplain land is the only space available for settlement particularly by poor, or migrant, people who are likely to lack the resources to build sound structures
- People trapped in buildings or on the roofs of buildings may die from exposure as illustrated by the Mozambique floods of February/March 2000

- Deaths can also occur where people are trapped in single story buildings, ground floor apartments, cellars or underground structures, such as railways or car parks which can pose a particular threat to life in urban areas. The growing tendency to multi-levelled cities where shopping centres and cinemas are below ground level is increasing this risk
- Metro systems present a particularly high risk, especially from flash floods but also from burst water mains and surcharged sewers
- Pedestrians unaware of the power of flood waters may be swept away. Abt *et al.*, (1989), in an experimental study, concluded that the safe limit would be a product of depth (metres) times velocity (metres/sec) of 1.0. Australian data give similar results (**Emergency Management Australia 1998**; New South Wales Government 1986), as does Finnish research (Reiter 2000). Eighty percent of the estimated 200 deaths in Monterrey, Mexico in 1988 were attributed to attempts to ford the flooded river (Vazquez *et al.*, 1997)
- Many deaths in floods occur because people attempt to drive through or away from flood waters and get swept away or trapped in their cars; their cars either then get swept away as a result of positive buoyancy (Bureau of Reclamation 1988; **Emergency Management Australia 1998**; New South Wales Government 1986; Reiter 2000) or stuck in the flood water (Table A.1). For example, in the Big Thompson flood in USA many of those who died were drivers who attempted to outrun the flash flood
- In Bangladesh, a significant number of deaths during floods are from snake bite as both people and reptiles take refuge in the same trees
- In flooded urban areas, people attempting to move about, particularly where flood waters are turbid or discoloured, may fall down blown manholes, into excavations or into ditches.

Jonkman *et al.* (2002) also show that applying different loss of life models gives very different results. For a region in the Netherlands with a population of 360,000 the predicted loss of life from the different models reviewed varied from just 72 to 87,564, with a mean of 20,775. The main difference, it appears, is due to whether the model used is one designed for a dambreak situation (not entirely inappropriate in the dike-dominated Netherlands) or one where the flood onset was slower and warnings could be longer.

### **Building collapse**

Buildings are a potential place of refuge in a flood and are frequently used as such by the people in a flood risk area. The partial or complete failure of the buildings in which they are sheltering to provide a safe refuge is consequently a significant factor in the number of deaths resulting from flooding. The probability that a building will partially or completely collapse in a flood is therefore an important factor.

Unfortunately, there is very limited data on the conditions that will induce the collapse of a building in a flood and that work is restricted very largely to the lightweight timber construction typical of domestic buildings in North America. There is limited data for masonry structures and none for concrete framed domestic buildings.

In each case, it is the combination of depth of flooding with the velocity of flooding that is important. The available data implies that it is the velocity of the flood flow that is

the critical factor and agree in defining a velocity of 2 metres a second as the critical velocity. Velocities in flash floods have been known to reach 15 metres a second.

Because the latter present less of an obstacle to the flood flows, it may be that the concrete framed structures are less likely collapse in a flood than load-bearing masonry buildings. However, localised scour around columns can be a significant problem (United States Army Corps of Engineers 1998).

That the more modern structures are often designed against earthquakes also probably reduces the probability that they will fail in a flood. Observing buildings on the Yangtze floodplain that were flooded following the failure of secondary dikes suggest that the criteria given in the figures are conservative. Because of surveys of flood losses are collected after each flood, China is in a particularly good position to identify the appropriate risk criteria. Traditional structures of dried mud/sun dried brick are probably best assumed to be destroyed in a flood but the same may not be true of bamboo or timber framed dwellings: in Bangladesh, a traditional place of refuge in a flood is under the roof space of the dwelling.

Unfortunately, a combination of depth and velocity is not the only mechanism that causes the structural failure of buildings. The debris carried by a flood in the form of trees and boulders can cause battering damage; one flood in Nepal deposited what is reported to be a 5000 tonne boulder (Oi, 1993). Buildings close to a watercourse frequently experience undermining as the flood erodes the channel and undercuts the buildings' foundations.

In addition to offering a possible place of refuge in a flood, damage to buildings is also one of the primary components of flood losses. Depth alone is sufficient – if its extreme - to cause damage to most structural types. Since most activities take place in buildings, the repair or reconstruction of buildings is a critical factor in the time taken after a flood for normal activities to resume.

Bridges quite frequently fail in a flood either because scour undermines the bridge supports or abutments, or because the openings are blocked by flood borne debris, the bridge then failing catastrophically under the build up of water. The flood wave, together with the debris carried with it, then poses a threat to the lives of those people downstream.

### **Loss of life through being swept away and drowned**

The failure of buildings as a place of refuge is not the only way in which a flood can pose a risk to the lives of those living or working on a floodplain. A number of studies have been undertaken to assess the limiting conditions under which it is safe to walk or drive through a flood (Abt *et al.*, 1989; Emergency Management Australia 1999; New South Wales Government 1986). A number of statistical analyses have also been undertaken of past floods in order to try to calculate the probability of death in a flood (DeKay and McClelland 1993; Graham 1999; Kraak 1994).

The difficulty in such analyses is in determining the appropriate divisor: the population in which the deaths occurred. It may be that whilst the number of people who were affected by the flood was several hundred thousand, most of the deaths occurred in one or two specific areas in which only a few hundred people were located. In those

specific areas, the probability of death may have been very high indeed. Graham's approach (1999) is a compromise between the statistical analysis of past floods and the use of depth or depth-velocity factors. It is geared towards assessing the risk of death from dam failure and is consequently geared towards escape being possible up steep valley sides (and vertical evacuation within buildings). Consequently, very short warning times (less than one hour) result in large reductions in the numbers of deaths.

### **C.3 Serious acute risk to health**

#### **Existing research on the health effects of flooding**

The human health consequences of floods, particularly relating to coastal flooding, can be severe. Health consequences from river or inland flooding would in many respects be the same e.g. those caused by the shock, disruption and inconvenience of the flood, as well as worry about future flooding. As [Baxter \*et al.\*](#), outline, there has been no large-scale research in the UK on the health effects from flooding to date. Bennet's 1970 study (Bennet, 1970), which demonstrated some significant effects, was the last systematic examination, although this only related to one town and one particular flood event. Research carried out in the 1980s further highlighted the seriousness of the so-called 'intangible' impacts of flooding on people's lives and wellbeing (Parker *et al.*, 1983; Green *et al.*, 1985; Green *et al.*, 1987; Green *et al.*, 1988; Tunstall and Bossman-Aggrey, 1988).

Several small-scale qualitative studies have been carried out since the flooding of Easter 1998 in eight communities in England and Wales affected by inland flooding (Tapsell, *et al.*, 1999; Tapsell, 2000; Tapsell and Tunstall, 2001).\* Three of these were communities flooded at Easter 1998, two were communities flooded in June 2000, and three were communities flooded in autumn 2000. The studies, which covered communities with varying socio-economic backgrounds and who experienced flood events of varying characteristics and impacts, have revealed some important consequences on people's health from river flooding. Although the results from these studies cannot be said to be representative of flooded populations generally due to the small samples involved (a total of 116 people), the same or very similar problems were reported in all eight communities which indicates a wider applicability of the findings.

What is not clear from the earlier studies is how long the various health effects reported following flooding were likely to continue. No longitudinal studies on the health effects of natural disasters could be found for the UK. Those studies that have been undertaken in the US and Europe have largely focused on the psychological impacts such as post-traumatic stress disorder and associated impairment to physical health (Holen, 1991; Hovanitz, 1993; Beck and Franke, 1996; Bland *et al.*, 1996).

#### **Factors contributing to serious consequences of flooding on human health**

Results from our qualitative research reveal that the adverse human health consequences of flooding are complex and may be far-reaching. However, not many of these effects are acute; they are more likely to be chronic.

The World Health Organisation defines good health as 'a state of complete physical, mental and social well-being, and not merely the absence of disease and infirmity' (World Health Organisation, 1948). Hazards such as floods can therefore be regarded as

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\* Some of this research is yet to be published.

potentially multi-strike stressors and health effects may result from a combination of some or all of the following factors:

- Characteristics of the flood event (depth, velocity, duration, timing etc.)
- Type of property e.g. Single storey, two storey etc.
- The amount and type of property damage and losses
- Whether flood warnings were received and acted upon
- Previous flood experience and awareness of risk
- Any coping strategies developed following previous flooding
- Having to leave home and live in temporary accommodation
- The clean-up and recovery process and associated household disruption
- Frustration and anxiety dealing with insurance companies, loss adjusters, builders and contractors
- Pre-existing health conditions and susceptibility
- Increased anxiety over the possible reoccurrence of the event
- A loss in the level of confidence in the authorities perceived to be responsible for providing flood protection and warnings
- Financial worries (especially for those not insured)
- A loss of the sense of security in the home
- An undermining of people's place identity and their sense of self (e.g. Through loss of memorabilia)
- Disruption of community life.

Additional components affecting the stress and health impacts of flooding may include socio-economic and cultural factors.

There appears to be a time dimension to the health impacts resulting from flooding. Health effects can be categorised as those resulting at the time of the flood or immediately after, those which develop in the days or early weeks following the flood, and those longer-term effects which may appear and/or last for months or even years after the flood. A common perception is that once the floodwaters have receded the problem is over. For many flood victims, this is when most of their problems begin. However, what we concentrate on here are the acute effects: those that happen during or immediately after the flooding.

### **Physical health effects during or immediately after flooding**

The effects on human health during or immediately after flooding reported by people flooded in 1998 and 2000 are summarised in Tables C.2 and C.3. These largely involve risk to life from fast-flowing floodwaters, general sprains from over exertion, consequences of being exposed to cold and damp environments or from coming into contact with contaminated floodwaters.

Severe coastal flooding can generally pose a more serious risk to life and threat of injury than fluvial flooding. However, people flooded by a high velocity river flood in North East England in 2000 spoke of fearing for their lives from drowning or being swept away by the floodwaters. Several people had to swim to save themselves or others, and some were knocked over by the force of the waters when trying to wade through them.

In the USA the main cause of death from flooding is of people attempting to drive or wade through fast-flowing floodwaters, and several people have also been killed in this way in the UK in recent years. As little as 30-40 cm of water can be enough to sweep even a strong and fit person off their feet. Even trying to wade through relatively calm waters, when deep, can be enough to disorient a person, and can pose the danger of injury from obstacles hidden beneath the waters or from dislodged manhole covers. There is therefore a need to increase public awareness of the dangers of trying to navigate through floodwaters.

### **Whose health is most at risk?**

To some extent everyone living or working in flood risk areas are vulnerable to the impacts of flooding. However, research literature indicates that certain groups within communities (e.g. the elderly, disabled, children, women, ethnic minorities, and those on low incomes) may be more vulnerable to the effects of disasters than others (Tapsell, *et al.*, 1999; Tapsell, 2000; Tapsell and Tunstall, 2001; Morrow, 1999; Fordham, 1998; Flynn and Nelson, 1998; Curle and Williams, 1996; Thompson, 1995; Ticehurst, *et al.*, 1996).

Vulnerability can be determined by the characteristics of a person or group in terms of their limited capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard (Blaikie, *et al.*, 1994). Consequently, these groups may suffer greater effects from a flood and may need special consideration by the authorities during the response and recovery periods. Two of these groups are discussed here.

#### *1. Children*

Children are often among those who are the most affected by a disaster (Flynn and Nelson, 1998). However, there has been little research on the impacts of natural disasters on children, and little evaluation of disaster-related interventions with children has been published (Vernberg and Vogel, 1993). Many of the parents who took part in our qualitative studies felt that their children's health had been seriously affected by the flooding (Tapsell and Tunstall 2001).

Fear for children's health and safety had led many parents to evacuate their children to relatives. This sometimes resulted in families being split up for long periods, which both children and parents found distressing. An important impact on children was the disruption to their familiar routines. This also meant having to miss out on regular activities because they were temporarily living elsewhere, or because the activity was cancelled due to the flooding.

Many parents reported that their children were anxious of a repeat flood event and became agitated during heavy rainfall. The loss of treasured possessions and even pets had deeply affected some of the children and a number of mothers reported behavioural problems with their children since the flooding. These included problems sleeping, nightmares, and tantrums. These behavioural changes were also noted in children following the 1990 North Wales floods in Towyn (Welsh Consumer Council, 1992; Hill and O'Brien, 1999).

A number of other issues were raised by parents, these included: the lack of advice for parents on how to deal with children after a disaster such as flooding, and the sort of impacts they might face; the lack of support and childcare facilities where parents

(especially single parents) could leave their children while they dealt with the clean up and recovery process; the lack of psychological or emotional support for children. Crèches and playgroups were set up in Towyn, following the 1990 flooding, which many parents found extremely helpful (Hill and O'Brien, 1999).

## *2. Women*

Disasters can also impact upon men and women in quite distinct and different ways (Tapsell, et al., 1999; Tapsell, 2000; Tapsell and Tunstall, 2001; Morrow, 1999; Fordham, 1998; Ketteridge and Fordham, 1995).

Women, even when in full or part-time employment, are traditionally responsible for the management of the household and may suffer more inconvenience when this is disrupted. Moreover, women's paid and unpaid care-giving responsibilities position them to emotionally and materially sustain their families throughout the flood and recovery process.

Men and women may also express their distress in different ways, however, socio-economic or ethnic differences may be as important, or even more important, than gender differences. In the majority of the households represented in our qualitative studies, it was the women's health that was said to have been most affected by the flooding. Men admitted feeling upset at not being able to do more during the flood event itself, as well as afterwards when working full-time and leaving their wives to cope with much of the recovery process.

### **Health impacts: some conclusions**

Although the risk to life and health would potentially be greater from a major coastal flood, inland flood events are already affecting many households and communities every year, and are likely to increase in the future. There are a number of actions that can be taken to mitigate the adverse impacts of flooding. For example, the Environment Agency has been improving its flood forecasting and warning systems, and increasing public awareness raising of flood risks through annual campaigns and 'Flood Awareness' weeks. There is now regular use of flood warnings on television and radio weather reports and promotion of the Environment Agency's Floodline information service.

Mediating factors between stress and health may include flood warning, coping strategies and social support; however, where flooding is unexpected, sudden and without warning, these may be weakly developed or non-existent. Self-help measures to reduce the damage to property and the stress caused by flooding are also being encouraged, thereby alleviating some of the negative consequences on people's health.

These measures include flood proofing of properties, development of a family Flood Plan along the lines of those widely used in the USA, and other community preparedness developments. Where feasible and cost-effective, flood alleviation schemes may also be considered, along with development control legislation to restrict new building in the floodplain. The UK is likely to need to adapt to increased risk of flood events in the future and to develop national coping strategies rather than those purely at the local or individual household levels.

Much more research is needed on trying to understand the complex health consequences which may result following flooding. Disease surveillance needs to be increased during floods, and information disseminated rapidly to dispel false rumours of public health epidemics. The longer-term psychological impacts on people's health and social well being particularly require more investigation, along with the issue of social support during the recovery period.

Evidence that socio-economic deprivation may be an important determinant of excess winter deaths due to cold, may also hold true for the health effects of flooding. The social and community dimensions of flooding, which can have significant impacts on households and individuals, are other factors often neglected in post-flood studies. Community activity often breaks down following serious flooding, and it can be many months before normal functioning is achieved. Moreover, some flood victims have spoken of a long-lasting deterioration in community life.

A final issue is that of the impacts on the health service from increased flooding in the future. Evidence from the USA following Hurricane Floyd in 1999 shows that health systems can also be badly affected by flood events, particularly if facilities are themselves located in floodplains, or when affected by disruptions to electricity, water supply, and transportation systems. The UK medical community also needs to be prepared to address these concerns and both the short and the long-term health needs of people who have been affected by flooding.

#### **C.4 Conclusions**

Loss of life in floods is not uncommon, but statistics for Europe show that it is becoming less common (probably owing to better warning systems).

The circumstances where loss of life in floods is likely are where velocities are high, flood onset is sudden as in flash floods, where flood waters are deep, and where natural or artificial protective structures fail by overtopping or collapse, and where extensive low lying densely populated areas are affected which mean that evacuation is difficult or protracted. These are circumstances where the threat is more immediate to the population at risk, and where the mediating influences are weak in one way or another.

Thus the main variables that we should be concerned with are:

- Water depth
- Water velocity
- Warning effectiveness
- Poor flood defence assets
- Large low-lying areas without proper evacuation.

Many of the circumstances leading serious harm to people are the same. Serious health impacts are likely where:

- Floods are sudden and without warning
- Pre-existing health status is low
- Recovery is impeded by a range of factors beyond the control of the flood victims
- The population at risk is elderly

- Community support is poor.

Thus these are the variables that are likely to predict where loss of life and major loss of health status are at a maximum.

**Table C.1 RESCDAM: preliminary results**  
(Source: Reiter 2000)

	Damage parameter $D \times v$ ( $m^2/sec$ )		
	Low	Medium	High
Children	< 0.1	0.1 – 0.25	> 0.25
Adults	< 0.3	0.3 – 0.70	> 0.70
Personal cars	< 0.9	0.9 – 1.50	> 1.50
Lightly constructed houses	1.3	1.3 – 2.50	> 2.50
Well constructed wooden houses	< 2.0; $v > 2.0$ m/s	2.0 – 5.0; $v > 2.0$ m/s	> 5.00
Brick houses	< 3.0; $v > 2.0$ m/s	3.0 – 7.0; $v > 2.0$ m/s	> 7.00

**Table C.2 Physical health effects reported during, or immediately after, Easter 1998 and summer and autumn 2000 floods**

Injuries from being knocked over by floodwaters or thrown against hard objects, or from being struck by moving objects
Injuries from over-exertion during the flood e.g. sprains
Hypothermia
Fear of electric shocks (although none were reported)
Cold, coughs, flu
Headaches
Sore throats or throat infections
Skin irritations e.g. rashes
Shock

**Table C.3 Serious health impacts from floods: summary results from the focus group surveys in the north east of England following the spring 2000 floods**  
(focus groups held in October/November 2000).

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**Key summary points: attitudes, stresses and behaviour before the flooding**

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- Before the flooding there was little awareness or expectation of the risk of serious flooding in Todmorden and West Auckland and no awareness in South Church
- Although some people had experienced past flooding in their properties in Todmorden and West Auckland, in only a few of these cases was this serious
- The majority of people were not prepared to cope with the flooding
- People generally felt that the risk of flooding should have been made clearer by the Agency.

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**Key summary points: attitudes, stresses and behaviour during the flooding**

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- During the flood people had been shocked at what was happening, and at the power, speed and depth of the floodwaters
- The risk to life from the flooding was highlighted by many people
- Most people had received informal warnings which had allowed some to save a few possessions; apart from this there was little people could do
- Some help was received from emergency services, friends and neighbours, but many people had to help themselves
- Various authorities, including the Agency, were criticised for their lack of support.

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**Key summary points: attitudes, stresses and behaviour after the flooding**

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- Damage to property and losses from the flood were extensive. The most important losses were irreplaceable personal items and memorabilia
  - For those who were evacuated from their homes the experience was stressful and several people had still not returned to their properties. Little rental accommodation was available locally
  - Those who did not evacuate faced months of living in damp and dusty conditions and the prospect of being surrounded by empty properties. Disruption to daily life was therefore great among both groups
  - Taking time off work to recover from the flood had caused problems for people, not least in the loss of income, but for a few people going to work offered some respite from the flood recovery process
  - Local authorities were generally criticised over what was perceived as insufficient support with the recovery process. The main forms of support required were suggested as being ‘manpower’, advice, and counselling. Voluntary support was generally well received
  - Key problems were experienced with loss adjusters and insurance companies, particularly regarding differing levels of service offered. Those without insurance faced additional problems
  - Builders and contractors repairing properties were also heavily criticised for their poor standards of service, unreliability, and unpleasant attitudes
  - Strong feelings were expressed of having to ‘fight’ for any advice and assistance in the recovery process. The effects of this had significant implications for people’s health and well being.
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**Key summary points: health effects**

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- Many people had suffered from physical health problems since the flooding, often associated with coming into contact with contaminated floodwaters, living in damp properties, etc.
- Concern was expressed over the health risks from contaminated floodwaters and the associated lack of, or conflicting, advice given by various authorities on these health issues
- The majority of participants admitted to feeling extremely ‘stressed’ by the flooding and recovery process and some were displaying signs of common mental disorders associated with experiencing a traumatic event
- Anxiety during rainfall was common among focus group participants since the flooding, and many had adjusted their behaviour (e.g. by regularly monitoring the river levels) due to the fear of possible future flooding
- The most devastating aspects of the flooding were largely said to be: financial, no time for ‘living’, the loss of ‘everything people had worked hard for’, and feelings of helplessness.

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**Key summary points: security and community cohesion**

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- Issues related to future security concerned the fear of future flooding and the loss of security people now feel in their homes – no longer a safe refuge
- Homes no longer have the same meaning for people as they did before the flooding
- Many people felt the need to know how to protect their homes from any future flooding
- The media were perceived as being intrusive and insensitive following the flooding
- Significant adverse effects were demonstrated by the disruption to, and deterioration of, community life, particularly in West Auckland and South Church.

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**Key summary points: attitudes to the authorities**

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- The general feeling was that the various authorities had responded poorly following the flooding, particularly the local Council
- People had little confidence in the authorities to predict future flooding, provide timely warnings, or provide support
- The Environment Agency was the only agency perceived to be taking some actions, although these were frequently seen as being too little and too late
- The perception of focus group participants was that the authorities, including the Agency, had no real commitment to flood prevention
- Various factors were seen to have caused or exacerbated the flooding – some of these were accurate and some were not.

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**Key summary points: vulnerable groups**

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- Certain groups within the communities affected by the flooding were seen to have suffered more pronounced effects than others. These groups were thought to need particular support and consideration
  - The flood was perceived to have had significant impacts on children, women, the elderly and disabled, both physically and psychologically
  - Children were thought to have been ignored by the authorities in the aftermath of the flooding. Many were said to have been very upset at the loss of treasured possessions and the disruption of their daily routines. This had led to behavioural problems and increased anxiety levels during rainfall
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- Parents wanted to be given advice on how to deal with children after flooding and the sort of impacts they might face, and the availability of psychological or emotional support for children in the aftermath of flooding. A creche or child-care facilities where children could be left while parents were coping with the recovery period were also suggested
  - The flooding was seen to have had differential impacts upon men and women. Women were seen to be particularly affected by the flooding, both physically and psychologically. Single women were thought to have been taken advantage of by insurance companies and builders
  - Support for the elderly and disabled following the flooding was seen to be generally inadequate.
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## Appendix D

### European flood review

This report summarises existing information on the causes of death and serious harm to people during a flood, based on a review of floods in Europe.

Quantifying the number of deaths and injuries that are attributed to a flood requires a definition of the real reason for the death or the injury. This research takes into account all deaths and injuries that occurred as a result of the *flood event*, including the hazard that the water itself poses and the danger associated with the storm that caused the flood.

Between 1986 and 1995 natural disasters claimed the lives of 367,000 people in the world, of which 55% were due to flooding and 9% were due to wind storms (MR-G 1997). This research into the mechanisms that cause these deaths during a flood will therefore inform flood management and help to prevent such serious harm in the future. With the potential for climate change to cause a real increase in the frequency and magnitude of flooding in the UK, it is also important that the Environment Agency should be prepared for managing this risk.

The causes of death and serious injury during a range of floods in Europe over the last 50 years are summarised in Table D.2. The relationship between the number of deaths and the total number of people affected are shown on Figures D.1 (flash floods) and D.2 (all floods). There is scope for further analysis to identify this relationship for different types of flooding (e.g. coastal, lowland fluvial, upland fluvial, etc).

Comments on specific aspects of flooding arising from floods in Europe are given in the following sections.

#### D.1 Warning efficiency

- The consequence of a false alarm is always a loss of confidence, leading to reluctance and poor reaction of people in subsequent flood alerts (ICPR 2002)
- The timing of an alert is also important: “In January 1995, the flooding of the Meuse in Charlesville topped the record value of 1993 by 52 cm. The mounted floodwalls were overtopped and damage was nearly twice as high as in 1993. On principle, the forecasting of the flood wave was correct, but it arrived later than predicted so that the population no longer believed in the alert” (ICPR 2002)
- The content of the warning plays an important part in peoples’ reactions. For example, on the 21st September 1992, meteorological services transmitted a special message forecasting violent storms for the next few days in the south of France. Lacking as it was in precision and detail (it gave only imprecise event characteristics and the expected rainfall depth), the alarm did not prompt any special preparedness measures. On the next morning, 300 mm of water fell in a few hours on the north of the Vaucluse department. The floods killed 37 people and 15 people disappeared (Horlick-Jones et al, 1995)
- It is difficult to reach some people with the normal warning communication mechanisms. This includes all those mobile at the critical warning time; tourists,

business travellers, seasonal workers and those who are socially isolated such as the homeless and those trying to remain out of sight (Handmer 2002)

- The efficiency of the warning is rarely complete. A study of several flood events in England showed that the flood warning reached between 0 and 74% of the population with an average around 40 % (RIBAMOD 1997b).

## **D.2 Prevention and psychology of people**

- Hazard awareness: “a large fraction of the public is unfamiliar with the nature of risks to which they are exposed” (US NCR 2000). This lack of awareness can be due to lack of information but also to forgetting the previous flood event: “Shortly after a flood, people affected by it are highly aware of the risk. Without flooding, awareness of the latent hazard diminishes” (ICPR 2002). In general, only great disasters (e.g. Netherlands in 1953) are really remembered (ICPR 2002). If no flood is expected, “flood awareness is reduced to a minimum within 7 years after a flood event. The population at risk will again be unprepared for and thus surprised by the next flooding.” (ICPR 2002)
- False sense of security: “The structures [river and sea defences] often give people a false sense of security and make them forget that a risk still exists. They avoid thinking of the danger.” (MR-G 1997)
- People’s response to the warning and alert. Several factors influence this response, see Table D.1 (Horlick-Jones *et al* 1995)
- People’s behaviour. “Losses of life and limb are in particular due to wrong conduct” [3]. “In Switzerland, misconduct played an important role in 40% of the 67 casualties due to floods registered between 1972 and 2001” [3]. Several sources highlighted the dangerous behaviour of people curious of seeing the flood (“flood tourism”). People with the most dangerous behaviour are usually local residents, trying to get home and crossing the water [4], without realising the dangerous conditions
- The late arrival of help or the closure of communication can lead to the feeling of being abandoned by authorities, and can leave long lasting emotional scars (FMTDE 2000). The treatment and support for victims during and after a flood is therefore a factor in people’s mental well being.

## **D.3 Population characteristics**

The age of a person is an important factor in determining their risk to death or serious harm during a flood event. In the flood of November 1999 in southern France, 8 out of the 9 casualties in buildings were senior citizens (ICPR 2002).

There is no doubt that injured and disabled people are also more vulnerable to death and serious injury during a flood event. They are less mobile to escape from the hazard quickly.

## **D.4 Flood characteristics**

### **D.4.1 Water depth**

For a flood depth of 2m or more, measures of flood proofing property are effective in a few cases only (ICPR 2002). People are therefore more exposed to risk in their house. For example, “Great flood disasters comparable to that of 1953 in the Netherlands (91,800 casualties) or that of 1962 in Hamburg (315 casualties) are caused by widespread floods at great depth, when houses completely disappear below water [...] and safe refuges are too far away” (ICPR 2002).

A depth of 0.5m is sometimes enough to make a car float (ICPR 2002). A mere depth of 0.2 m is sufficient to considerably slow-down a car (Rantigny Station 2002), increasing the risk of roads being blocked.

### **D.4.2 Velocity**

The velocity of the water obviously influences how dangerous it is for people in the flow but also determines the concentration and size of debris in the water which increases the risks (MR-G 1997). For example, “In Switzerland, where widespread floods at great depth have not been experienced, large numbers of casualties result from the destruction of buildings following the impact of considerable dynamic forces (e.g. October 2000, 15 casualties)” (ICPR 2002).

### **D.4.3 Rate of water rise**

The speed with which the water rises depends on the type and nature of the flood. “This parameter determines the threat posed to persons inside and outside buildings” (ICPR 2002).

### **D.4.4 Type of flood**

- Flash floods lead to high number of deaths. They generally occur in mountain basins, with a short response time (<3h). The surprise factor is the main cause of death (RIBAMOD 1997a). Also they usually have a high flow velocity (see D.4.2)
- Lowland floods occur in large rivers and are less sudden than flash floods. Time is available for forecasting and warning (RIBAMOD 1997a). This type of flood generally causes death by drowning, but few injuries. The rate of death is usually lower than for flash floods, the damages being essentially material due to the high spatial extend of the flood (Catnatlive 2003)
- Coastal floods occur as a result of high tides and storm surges. One of the major risks associated with this type of flood is people being swept away by waves crashing over the sea wall and drowning as a result. This is likely to happen when people become curious and go to the sea front to watch the spectacle of huge waves. This occurs quite frequently, for example in the UK floods of 2002 when a man was swept off Brighton pier and was killed (BBC 2003)

## **D.5 Influence of conditions of exposure**

The conditions of exposure during a flood have a significant influence on the vulnerability to death or serious harm and will also largely determine the way in which a person is killed or harmed. The following points outline the risks associated with different exposures to the flood. The relative vulnerability of these situations can be

demonstrated by examining the causes of death during the floods of November 1999 in southern France. Twenty-four people died in this event; 10 of which died in cars, 9 in buildings and 3 in the open air (ICPR 2002).

#### **D.5.1 In the open air**

“In the open air, people are exposed to the impacting forces without any protection. Darkness and cold reduce the possibilities of orientation and of keeping above water for a longer time. With a lack of experience, the impact of flow velocity is mostly underestimated” (ICPR 2002).

#### **D.5.2 On camp site**

Campsites are vulnerable to destruction during a flood and do not provide a safe place for people to stay. Several events demonstrate the great exposure of campsites, especially in the case of high velocity flow. For example; two people died when flood inundated a camp site in July 2001 in the west of France (FMTDE 2002) and in the 1953 storm surge, the coastal flood on the east coast of the UK killed people in camp sites (Eastern Daily Press 1953).

“In camp sites, people are protected as little as in open air. To aggravate the situation, in a tent, a caravan or any comparable provisional accommodation the hazard is not recognised as such and at night, people may be taken by surprise” (ICPR 2002). This was the situation in the 1987 floods in Savoie in the French Alps, where people camped in the course of the water discharge and 23 people died in the event (ICPR 2002).

#### **D.5.3 In a vehicle**

Staying in a vehicle is a great source of risk, as their buoyancy (see B.3.1) is usually underestimated. About half of all flash flood related deaths in the US are a result of people being trapped in vehicles (MITCH 2002).

#### **D.5.4 In a building**

Buildings are usually the best refuges during a flood. Some sources of danger still remain:

- gas leakage and electrocution (MR-G 1997)
- escape of dangerous liquids (MR-G 1997)
- being trapped if there is no floor available above the maximum flood level, if the stairs are blocked, or for elderly and disabled people. For example, two people died in Brig in Switzerland in 1993 as they were trapped in rooms without any possibility of escaping to higher floor. One person died in Boll in Switzerland in 1987 when they were trapped in basement or underground garage (ICPR 2002)
- use of elevators (Augsburg in Germany, 1999, divers rescued 1 person (ICPR 2002)
- poor quality buildings can be just as vulnerable as campsites. They cannot withstand the hydraulic pressures placed on the structure during the flood.

### **D.6 Other factors**

During a flood event the risks to life are not simply associated with drowning in the water. Other factors also present a hazard to people.

- Falling trees. For example, one man was killed by a falling tree in the 2001 flood in Vosges in France (FMTDE 2002)

- Mudslides. One person was killed in a mudslide in the July 2001 flood in the south west of France (FMTDE 2002)
- Being hit by flying debris. Also in France in 2001, the storm associated with the flood resulted in extensive damage to buildings. People were killed by wind swept debris hitting them, such as roof tiles (FMTDE 2002).

## **D.7 Long term risks**

A flood event can cause death and serious harm to people as a result of the long-term ramifications of the event. These risks are generally outside the scope of this project, but include:

- Long periods of ground saturation and direct damage to crops. Where a flood inundates agricultural land, there may be a following food supply shortage. This problem may be more relevant for self-sufficient communities but will also have an impact on the economy of other areas. A direct loss of food may result in malnutrition and associated illnesses and a down turn in the economy may cause poverty-related harm to health
- Water and mud in houses causing poor living conditions. Unsanitary living environments result in the quick spread of disease and illness
- Destruction of water distribution systems, sewerage and water treatment plants. The impact to the water supply is a critical factor in the aftermath of the flood. Death, disease and illness will be widespread if people do not have access to clean water and if sewage is not removed from their living space
- High sediment load in rivers following the event degrades the water quality so that it is not safe to use directly and more difficult and expensive to treat. Again the water supply quality is a critical parameter to people's health after the flood.

An example of the importance of the clean up operation after the flood can be drawn from the Prague 2002 floods, where the authorities undertook specialist cleaning of homes and buildings after the flood in order to minimise health risk. This involved the disinfection of buildings and roads and the removal of perishable foods from properties that had been evacuated. These actions ensured that there was no outbreak of infection and disease after the flood (Bowker 2003).

## **D.8 References**

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## RISK COMMUNICATION AND WARNING SYSTEMS

**Table D.1 Major Factors covarying with Warning Response**  
(Source: Sorenson, 1993)

Factor	Direction: As factor increases, response	Level of Empirical Support
Physical cues	Increases	High
Social cues	Increases	High
Perceived risk	Increases	Moderate
Knowledge of hazard	Increases	High
Experience	Mixed	High
Education	Increases	High
Family Plan	Increases	High
Fatalistic beliefs	Decreases	Low
Resource level	Increases	Moderate
Family united	Increases	High
Family size	Increases	Moderate
Kin relations (number)	Increases	High
Community involvement	Increases	High
Ethnic group member	Decreases	High
Age	Mixed	High
Socio-economic status	Increases	High
Gender (female)	Increases	Moderate
Having children	Increases	Moderate
Channel: Electronic	Mixed	Low
Channel: Media	Mixed	Low
Channel: Siren	Decreases	Low
Personal contact	Increases	High
Proximity to threat	Increases	Low
Message specificity	Increases	High
Number of channels	Increases	Low
Frequency	Increases	High
Message consistency	Increases	High
Message certainty	Increases	High
Officialness of source	Increases	High
Fear of looting	Decreases	Moderate
Time to impact	Decreases	Moderate
Source familiarity	Increases	High

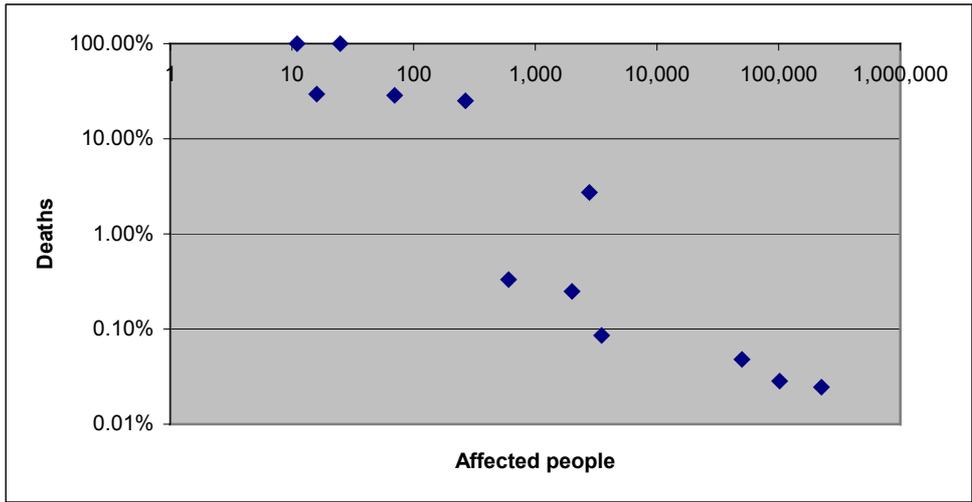


**Table D2 A selection of floods in Europe, 1953 – 2002**

Year	Month	Day	Nature of the event	Characteristic of events	Location	Number of dead	Injured	Affected (injured + other)	Causes of dead or injuries	Other	Photo	Source of information
1953	2		Coastal flood	Storm surge combined with high tides	Norfolk Coast, England, Holland.	England: 100 deaths. Holland: 142 deaths.			1. Sea broke through dunes and swept away buildings. 2. People unwilling to leave their houses. 3. Caravan site and houses near the sea were destroyed and people in them killed. 4. People trapped in prefabricated houses. 5. Drowning. 6. People lived in bungalows and had nowhere to escape to.	Buildings and infrastructure destroyed.		Eastern Daily Press. 02-Feb-1953.
1953			Coastal flood	For 3 days a strong northwesterly wind drove almost 500,000,000 m3 of water into the southern part of the North sea. Fifty dykes in the Netherlands broke. Thousands of km2 were under water, in some places several metres deep.	Netherlands	1800 deaths			Drowned.	3000 houses destroyed and 40,000 badly damaged. Millions of hectares of valuable farmland was washed away. 1,600 km2 of land was swamped. The overall loss exceeded half a billion dollars.		"Flooding and insurance" Münchener Rückversicherungs-Gesellschaft
1953	1	31	Flooding on the Thames and the Wash		England	2000 300 deaths		3000000	Break of a polder			www.cred.be
1962	2	16	Storm surge, coastal flood	For 45 h, a heavy northwesterly storm with windspeed of up to 150km/h drove masses of water from the North sea into their tributaries. The storm surge reached its climax at 22:45 on 18th February, when the elevated water level caused by the wind concurred with high tide.	Hamburg, North of Germany	350 deaths			Drowned by the water of the Elbe.	In more than 60 places, the sea defences, with a total length of more than 100km, broke or were overtopped. 125km2 - or 45% of the city area - was submerged. Overall loss equivalent to 3 billion \$ in today's term.		"Flooding and insurance" Münchener Rückversicherungs-Gesellschaft
1962	9	25 or 27	Flash flood	Flash flood produced in the Llobregat and Besos rivers and their tributaries. A total rainfall of 212 mm was recorded in less than 3 hours, with a maximum intensity of 6mm/min.	Catalonia - Barcelona	342 More than 800 deaths			Due to flash floods - the deaths occurred within 2 hours			www.cred.be http://www.am.ub.es/hbarrera/Spagnalepisodes/1962.pdf www.cred.be
1962	9					474-800						
1966	11	3-4	Flood	A third of the average annual precipitation had fallen in 24 hours, making the Arno rise at a rate of 1 m per hour.	Florence							"Flooding and insurance" Münchener Rückversicherungs-Gesellschaft
1967	11	26	Flash flood	Due to rainstorm.	Area of Lisbon, Portugal, Romania (Especially East of country)	116 462	100 1000	100100 1100				www.cred.be
1970	11	11	Flood			215		238755				www.cred.be
1973	10	19	Flash flood		Granada, Almeria (Spain)	500 killed						www.cred.be
1992	9	22	Flash flood	up to 300 mm in 3 hours	Vaison-la-romaine	38 deaths			Numerous houses in the town were completely devastated. Throughout the region there was severe damage to the infrastructure and power lines. The insured losses came to more than 300 million \$		In book	"Flooding and insurance" Münchener Rückversicherungs-Gesellschaft
1992	9	22	"						On the 21st September 1992, meteorological services transmitted a special message forecasting violent storms for the following days. Lacking as it was in precision and detail, the alarm did not prompt any special preparedness measures			Natural risk and civil protection, edited by Tom Horlick-Jones, Aniello Amendola and Riccardo Casale. (ESFN Spoon) 1995
1994	11	4-6	Flood		Southern Alps	67 in the region 64 deaths		200	Drowning. Worst flood since 1910 in North Italy.	10,000 homeless. Overall loss above 12 billion dollars		www.cred.be "Flooding and insurance" Münchener Rückversicherungs-Gesellschaft
1997	7		Flash flood in headwaters, lowland flood downstream.	Flood, Odra/Oder River. Return period > 1 in 100yrs. Little warning in headwaters in Czech Rep and Poland, more warning time in Germany.	Czech Republic, Poland, Germany	Czech Rep: 80 deaths. Poland: 54 deaths. Germany: no deaths.		Italy: 17300 (10300 homeless)	Flood warning did not reach people. People did not believe the flood warning. Water flooded places that have usually been safe in the past.	People evacuated: Czech Rep: 26,500 Poland: 162,500 Germany: 6,500. Economic loss estimates: Czech Rep: DM (1-4)bn. Poland: DM (5-6)bn. Germany: DM (0.5-1.2)bn.		Bronstert, A. et al. (eds.) (1999). <i>Proceedings of the European Expert Meeting on the Oder Flood 1997</i> . European Commission.
1997	7	30				Czech rep : 2409		Czech Rep: 102107 (11973 homeless). Poland: 224500 (62000 homeless). Germany: 15000.				www.cred.be
2001	1	5	Storm		Vosges (France)	1 death (Forest worker)			By falling tree			"Les événements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environment

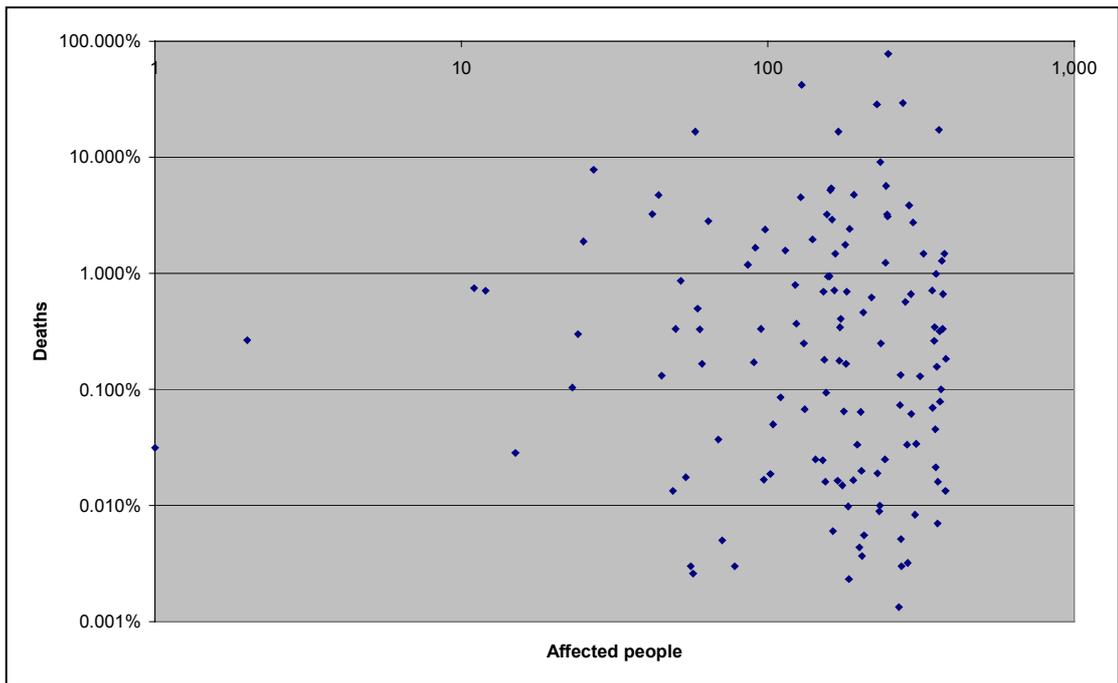
**Table D2 A selection of floods in Europe, 1953 – 2002 (continued)**

Year	Month	Day	Nature of the event	Characteristic of events	Location	Number of dead	Injured	Affected (injured + other)	Causes of dead or injuries	Other	Photo	Source of information
2001	3	13-30	Generalised Flood		France	4 deaths			Victims usually by imprudence.	Building caving in, 634 towns flooded.		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	7	5-6	Flood		South-West of France	1 death			Mudslide	National road blocked, Evacuated camp site		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	7	6-8	Flood		Somme (North of France)					450 houses affected		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	7	06	Storm, Strong wind, hail	Wind other 110km/h	East of France	13	84		Mainly by falling tree and tiles.	Several 10,000 houses without electricity.		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	7	27	Flood, Storm		West of France	2 deaths			By storm on a camp site			"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	8	15	Storm, Wind		West of France	2 deaths			Storm and falling tree			"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	10	6-7	Flood	300 mm of rain in 24h.	Gard (South of France)	2 deaths (1 fireman and 1 car driver)				Roads and railway blocked.		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	10	9	Flood		South of France	0	2			50,000 houses affected		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	10	20	Flood		Centre of France	1 death			Taken away by the flow			"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	10	21	Flood, wind	130mm of rain in 4h at Livron, 120km/h wind	South of France					Several 100 houses flooded, Road blocked.		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2001	12	29-31	Flood		East of France	1 deaths			Mudslide	Roads blocked, Bank break		"Les evenements naturels dommageables en France et dans le monde en 2001" French Ministry of territory development and environnement
2002	8	6-7 and 11-12	Flood	total rainfall = 150-200 and up to 300 mm in some sites. The first wave of rainfall caused 10 to 20, exoptiomally 100-year floods. When the second wave of rainfall followed, the first one rivers and soil were still full of water and therefore a response of runoff was very strong and quick. Peak discharges in majority of rivers reached or exceeded 100-year flood and in some rivers 1000-year flood.	Czech Republic	15 deaths				100 towns and villages were fully flooded, 350 partly flooded. 1.6 million people affected by the flood, 220000 moved from their houses.		Preliminary information on the catastrophic flood in the Czech Republic. From James Hunt 18/10/02. In yellow folder MCS0433_PMB_PJI
2002	8		Flood	River Elbe reached unprecedented levels.	Germany				1 death was a 71-year old man who drowned. 2 adults and a child were missing after being swept away by a cascade of mud and water	30,000 residents left their houses		cnn.com, August 15, 2002
2002	8		"		"	14 death across western Germany				30000 evacuated, in total 100000 have left their homes for more secure area		bbc.co.uk 17th August 2002
2002	8		"		"	18 death across western Germany						bbc.co.uk 18th August 2002
2002	8		Flood		Russia - Border of the black sea	58 deaths			Many of the 58 victims were swept away by swiftly moving water			cnn.com, August 15, 2002
2002	9			600mm rain during the event	South of France	26 deaths			11 drowned after a dambreak in Aramon. Lack of warning. Bot of lightning killed 1 man. 1 firefighter died from injuries after having rescued a couple trapped in a car			enn.com, 11 sept 2002
2002	9		Flash flood		"	At least 20 deaths and 12 people missing.				3000 people out of their home		bbc.co.uk, 11 sept 2002
2002	9		"		"	Deaths revised down from 26 to 21.				About 250 people evacuated from their home, 900 were forced to flee to temporary shelter.		cnn.com, 11 sept 2002
2002	9	8-9	Flash flood	"Cevenoles" rainfall. From 100 to 687mm (Ardèche) in the region.	South of France (departement of Herault, Lozere, Gard, Ardèche, Drôme, Vaucluse and Bouche du Rhone)	23 deaths			Majority due to imprudence : people trying to reach their home while road flooded. Usually, local people less careful than tourist or traveller. Witness told that people didn't want to evacuate before event because they didn't take the warning seriously.	Buildings destroyed, car (and trucks) taken away on several 100 m, tarmac ripped off the road, bridge collapsed,	Numerous digital photo available on website	http://perso.wanadoo.fr/meteo/special09-09-02-cevenol (personal site from a meteorologist from the Rantigny Station)
2002	9	8-9	"		"	24	50000		1 elderly woman died drowned in her house, 1 killed in a mudslide, 2 killed by lightning bolt	450 million euro of insured damages		http://cathalivre.free.fr/priv/Dossiers%20Force%2002/02/dossier_france_gard.htm www.ftsa.fr



**Figure D.1 Deaths as a percentage of people affected: flash floods**

(Compiled using data from Table B.1, and the cred database using 7 floods from France, Ireland, Spain, UK and USA)



**Figure D.2 Deaths as a percentage of people affected: all floods**

(Source: cred database without distinguishing between different types of floods. Events from Europe, USA and Russia)



## Appendix E

### Case Studies

#### **Risk to life and serious harm from floods: The Case Study of West Hampstead, August 7<sup>th</sup> 2002**

##### **Location and meteorological/oceanographic circumstances**

On August 7<sup>th</sup> 2002 a severe summer storm hit Hampstead Heath in North London. Some 150mm of rain fell in 2 hours (**check**) in a very large thunderstorm event. Runoff was extremely rapid across the urban area, trending south-westwards towards West Hampstead. Here the main sewerage systems involve both the normal urban drainage, the connecting highway and foul drains, and the North West Storm Relief Sewer that had been installed by Thames Water following a comparable event in July 1975. This sewer is 2.5 m in diameter, and is located approximately 9 metres underground.

The return period of the flooding was probably 1:40 (see below) but the return period of the storm has been estimated at 1:145 years.

This area had been flooded before, as indicated above, in both 1975 and in 1927. The circumstances were all similar: a summer thunderstorm event, creating rapid overland flow, and an urban drainage system that is not designed for this rarity of event and which was overwhelmed by the volume of flood water that was generated.

##### **The immediate local flood generating mechanisms, flood characteristics and warning effectiveness**

The residents of the area report (Camden Borough Council 2002, 2003a and b) that there was no warning of the flooding, which occurred in late afternoon. Much of the flooding was to basement flats, and the flooding occurred as both overland flow coming into the flats from the roads or gardens, or flooding emanating from the WCs and other connections to the sewer system.

The 'catchment' has its headwaters on Hampstead Heath, and its lowest points in the late 19<sup>th</sup> century urban area bounded by railway lines and main roads. Most of the floodwaters flowed down these roads, down the neighbouring streets, were ponded against railway walls, and accumulated at the low points in the catchment. This is where the access to the North West Storm Relief Sewer is located, but the sewer was full and indeed surcharged within about one hour after the peak of the rainfall.

##### **The nature and severity of the adverse impacts**

In this flood event at least 100 houses were flooded. Some had their basements flooded to at least 1.0 metre, and the floodwaters were contaminated with raw sewage as much of the flooding was caused by inadequate sewer discharge. Some of the properties suffered damage in excess of £40,000 in terms of reinstatement costs. Some residents were still not back in their flats and houses in March 2003.

The most serious impact of the flooding was experienced by Miss Keller, aged 80, who

had occupied her garden flat alone for the last 40 years. She had a number of age-related infirmities (glaucoma; cataracts) and most were related to chronic problems that she had lived with for many years: osteo-arthritis, poorly functioning kidneys, such that she was becoming more disabled as she got older. She relied on a wheelchair lift to get her to pavement level, but she was independent, mentally very strong, and had a wide circle of friends.

When they came, the floodwaters pushed out the window to her bedroom on the street side of the flat. Miss Keller was “swept off her feet” by a wave of sewage and water. She tried to find something to grab on to, and at one point was completely submerged. She “managed to fight her way to the surface” and got herself on to the up-turned sofa where she was found by a passer-by who broke through the front door and managed to get Miss Keller and her cat out. Somehow this person carried her up to the pavement where she waited in heavy rain for an ambulance, suffering from a dislocated hip. She was taken to St Mary’s Hospital where she remained for a week.

The night before she was discharge to a residential home, she was clearly suffering from an infection because she had vomiting and diarrhoea. At the residential home her illness was not treated properly, and she did not see a doctor for three days. By then she had developed a very severe chest infection, and was showing signs of kidney failure. She was admitted to the Intensive Treatment ward of the Royal Free Hospital where, after a week of extreme distress and discomfort, she died on August 25<sup>th</sup> (18 days after the flood event).

#### **The population at risk: contributory factors affecting vulnerability**

Many of the people affected lived in basement flats without non-return sewerage valves. Several were elderly, or lived alone. The worst affected had some pre-existing health problems, or were relatively immobile.

Although Miss Keller (see above) had lived there a long time, and had indeed experienced the flood in 1975, this was not true about the majority of the population: this is an area where turnover of residents is high in the rented accommodation that dominates the West Hampstead area. Thus knowledge of the flooding potential and the dangers inherent was very sparse indeed.

Many of the flats affected have only one means of escape (the front door), thus exacerbating risk. From the basement flats it is difficult to call for help. The local fire brigade centre was itself flooded, so help of this kind had to come from Paddington (some miles away).

There was no warning of the flooding and the velocity of floodwaters, flowing down from the Heath, was high. The main sewers soon became surcharged an unable to accommodate the volumes of water from the overland flow.

#### **Lessons learned about the factors affecting risk to life and serious harm from floods**

Loss of life in floods is a function of the nature of the flooding, the character of the population, and the occurrence of ‘accidents’.

*About the flood characteristics*

Very rapid urban runoff is dangerous. Basement flats in flood-affected areas are potentially death traps. In multi-story dwellings (often 4 storeys high in West Hampstead) it is more likely than not that these basement flats will be occupied by elderly pensioners (a) because these flats are cheap and (b) because they cannot manage the stairs to the higher floors.

*About the population characteristics*

Urban areas such as West Hampstead are occupied by people who come and go with high rates of turnover. They cannot be expected to have knowledge of past floods. This means they will not know what to do in dangerous events, and will not expect to be flooded out.

*'Accidents' and other contributory factors*

Miss Keller was trapped in a basement flat. She was released prematurely from hospital. The treatment that Miss Keller received at the residential home was not satisfactory.

**Data sources, and documents/references consulted**

London Borough of Camden, Floods Scrutiny Panel, evidence given by residents (London Borough of Camden, 2002, 2003a and b).

**Risk to life and serious harm from floods:  
The Case Study of Herault, Vaucluse and Gard (South of France), 8-9 September 2002**

**Location and meteorological/oceanographic circumstances**

Event of the 8-9 September 2002 in department of Herault, Vaucluse and Gard (South of France).

Heavy rainfall are usual on the region in September-October: cool air coming from the north pole meets the warm damp air from the Mediterranean other the Cevennes (moderated-mountainous region). The mountains block the cloud leading to concentrated rainfall over the region.

For this event, the storm was particularly concentrated and stayed stationary for almost 24 hrs.

**The immediate local flood generating mechanisms, flood characteristics and warning effectiveness**

**Forecasting.** Meteorological models were accurate as for the location and duration of the storm, but only forecasted 100 mm of rain for the event.

**Warning.** The meteorological flash on TV and radio before the weekend talked only of heavy rainfall, without mentioning the flood risk. The first alert occurred the morning of Sunday 8 (orange alert, level 3/4), but lead to little reaction from people. The second alert (red alert, level 4/4) occurred Monday at 1:37 am, but was too late, as the flooding was already severe. Globally, the warning was too late and inefficient.

**Flood generating.** A rain of unusual intensity (up to 200mm/hr) lead to a flash flood. Between 100mm and 600mm of rainfall during the event (24hrs) depending on the location.

**The nature and severity of the adverse impacts including number of deaths and injuries**

**Human impacts:** about 24 deaths, 50 000 people affected.

**Material impacts:** buildings, bridges and road destroyed. Insured losses: 450 million Euro.

**The population at risk: contributory factors affecting vulnerability**

- Lack of warning.
- Poor warning reception.
- Imprudence: people try to reach their home while the roads are flooded. A witness reported that local people are usually less careful than tourist or traveller.
- Staying in the car increases the risk, as well as crossing streams.
- One elderly woman died, drowning in her house.
- Housing near some watercourses were swept away.

**Lessons learned about the factors affecting risk to life and serious harm from floods**

**About the flood characteristics (depth, velocity, suddenness of flooding, duration, flood warning)**

- 24h of exceptional rainfall;
- high depth, usually up to 2-3 m (a photo shows a depth of 20 m at a bridge);
- high velocity (water carrying stones, trees, cars and trucks and denuding the rock);
- warning too late and ineffective.

**About the population characteristics (age, health, socio-economic factors, type of housing)**

- normally mixed population;
- type of housing: the houses swept away seemed to be reasonably strong, the location of the houses and the velocity of the flow were the determinant factors.

**About the location (type/size of floodplain, defences)**

- narrow floodplain, surrounded by hills;
- defences undersized compared to the magnitude of the event.

**Data sources, and documents/references consulted**

- enn.com
- bbc.co.uk
- cnn.com
- <http://perso.wanadoo.fr/meteo/special/09-09-02-cevenol> (personal communication from a meteorologist from the Rantigny Station)
- [http://catnatlive.free.fr/prive/Dossiers%20Frce%202002/dossier\\_france\\_gard.htm](http://catnatlive.free.fr/prive/Dossiers%20Frce%202002/dossier_france_gard.htm)
- [www.ffsa.fr](http://www.ffsa.fr) (French insurance organisation)

**Risk to life and serious harm from floods:  
The Case Study of the UK Autumn 2000 floods**

**Location and meteorological/oceanographic circumstances**

A series of high magnitude rainfalls over the UK caused flooding of almost 700 locations in England and Wales. Some locations were flooded more than once in Autumn 2000. Successive rainfall events over a seven week period resulted in the waterlogging of catchments so that rivers responded rapidly to further rainfall even if it was not of great magnitude.

503mm of rain fell in September, October and November. The highest daily rainfall total was equivalent to a 1 in 300 year return period.

Maximum 150 words

**The immediate local flood generating mechanisms, flood characteristics and warning effectiveness**

- Surface water drainage was inadequate for the high-risk rainfall events.
- 11,000 people evacuated. Some of those evacuated did flood and other didn't [1, 5].
- 1,437 flood warnings were issued, of which 190 were Severe Flood Warnings. There was no flood warning in North Wales. Overall, of the 1900 separate properties that were flooded, 1500 did not receive a flood warning.
- The Automatic Voice Messaging system delivered messages to 85,715 locations, with a success rate of 75- 85%.
- 99.99% of callers to the Environment Agency Floodline received a recorded flood warning message. However, at peak times, only 30% of calls were being answered and handled successfully by call centre operators.

Maximum 150 words

**The nature and severity of the adverse impacts including number of deaths and injuries**

- DEFRA state there were no deaths directly attributable to the floods [7].
- The EA state two people died in the floods [7].
- The media reported at least 9 inland water drownings. 1. A woman drowned in the River Tavy on a canoe trip. 2. A man was presumed drowned in a tributary of the River Nene when he tried to save a dog. 3. A shoplifter was presumed drowned when chased by security staff and falling into the River Tame. 4. The BBC reported a teenager falling into a flooded river in Manchester [3]. 5-8. 4 people died in their cars, 2 by crashing as a result of stormy weather [4] and 2 by driving off a bridge into the flooded river [4, 7]. 9. One person died when swept into the North Sea as walking along coastline [6].
- 10,000 properties flooded [1, 5]
- Flood damage was between £700 and £750 million (from The Association of British Insurers (ABI)
- Waterlogging caused subsidence and some houses had to be demolished [2].

Maximum 250 words

**The population at risk: contributory factors affecting vulnerability**

Vulnerability of people was reduced by flood warning systems. Communication

between the EA and professional partners, the media and the public was good and had improved from the lessons learned since the Easter 1998 floods. The EA held a public awareness campaign a month before the floods started to raise the profile of Floodline and flood preparedness. During the floods there was increased usage of the EA web site.

The EA public awareness campaign targeted particular socio-economic groups and those with sight or hearing impairment known to be at risk.

Maximum 250 words

### **Lessons learned about the factors affecting risk to life and serious harm from floods**

About the flood characteristics (depth, velocity, suddenness of flooding, duration, flood warning)

- 28% flooding due to coastal floods: overtopping, outflanking or failure of defences.
- 40% flooding due to coastal floods where no defences.
- 32% flooding due to river floods: inadequate local surface water drainage and third party defences.

About the population characteristics (age, health, socio economic factors, type of housing)

- Flooding affected so many locations that the population characteristics were not particular to a single demographic. A cross section of society was affected.

About the location (type/size of floodplain, defences)

- 58% properties flooded were in locations where there were no flood defences

Maximum 150 words

### **Data sources, and documents/references consulted**

[1] Environment Agency (2001) *Lessons Learned Autumn 2000 Floods*. Environment Agency, Bristol.

[2] <http://news.bbc.co.uk/1/hi/uk/1120108.stm> Report from 20 Jan 2001.

[3] <http://news.bbc.co.uk/1/hi/uk/1070145.stm>

[4] <http://news.bbc.co.uk/1/hi/uk/1062356.stm>

[5] The Comptroller and Auditor General (March 2001) *Inland Flood Defence*. National Audit Office, London.

[6] <http://news.bbc.co.uk/1/hi/uk/1154017.stm>

[7] Kelman, I. (2003) UK Drownings.

<http://www.cfspress.com/KelmanUKDrownings.pdf>

Maximum 150 words

**Risk to life and serious harm from floods:  
The Case Study of Weesenstein, Southern Germany, 12<sup>th</sup> August 2002**

**Location and meteorological/oceanographic circumstances**

The village of Weesenstein is on the River Muglitz, a tributary of the Elbe near Dresden. The river is contained in a narrow steep valley.

The village of Weesenstein consists of about 30 houses in the valley bottom, and an impressive castle on a rock outcrop just upstream of the village. The catchment area is about 200km<sup>2</sup> and there is a dam upstream with a catchment area of about 11km<sup>2</sup>.

About 300mm of rain fell in the vicinity on 11 to 13 August 2002. The rain was particularly heavy over the Muglitz catchment but also affected a very large area in Germany and the Czech Republic, causing severe record flood levels on the Elbe at Dresden.

Maximum 150 words

**The immediate local flood generating mechanisms, flood characteristics and warning effectiveness**

The heavy rain caused flash flooding. This was exacerbated by the failure of the dam on 12 August 2002. The retention volume of the dam is about 50,000 m<sup>3</sup>.

The flood depth on the floodplain was of the order of 2 to 4 metres. A rough estimate suggests flow velocities might be of the order of 5m/s or greater. A better estimate could be obtained by hydraulic calculation based on valley geometry and observed flood levels.

It is understood that there was no flood warning – the first that the residents knew about the flood was when it started to occur. As the valley is narrow, the escape route is very short.

Maximum 150 words

**The nature and severity of the adverse impacts including number of deaths and injuries**

Six houses were completely destroyed and several were badly damaged. Four people died. Many people survived by staying in the upper storey of their houses. One family survived by sitting on the one remaining wall of their collapsed house.

The houses were large and of sturdy construction, typical of the Region.

Maximum 250 words

**The population at risk: contributory factors affecting vulnerability**

The population of the village is mixed and includes both old and young people. There were no particular social circumstances contributing to the flooding. The main factors were the ferocity of the flood flows and debris carried by the river.

Maximum 250 words

**Lessons learned about the factors affecting risk to life and serious harm from floods**

About the flood characteristics (depth, velocity, suddenness of flooding, duration, flood warning)

Depth 2 to 4 metres on the floodplain. High velocity. Sudden flooding. Duration less than one day. No flood warning.

About the population characteristics (age, health, socio economic factors, type of housing)

Mixed population. Generally well off. Well build houses of mixed age and traditional design. The main factor leading to collapse was location on floodplain and exposure to high velocity and deep flows.

About the location (type/size of floodplain, defences)

Steep narrow floodplain (c50m wide on both banks). No defences although the river has been channelised.

Maximum 150 words

**Data sources, and documents/references consulted**

None – site visit during MITCH workshop

Maximum 150 words

**Risk to life and serious harm from floods:  
The Case Study of the 1953 flood on the East Coast of the UK**

This case study provides informal notes on the 1953 flood deaths. Importantly, most deaths appear to have occurred within a few hundred metres of coastal defence breaches.

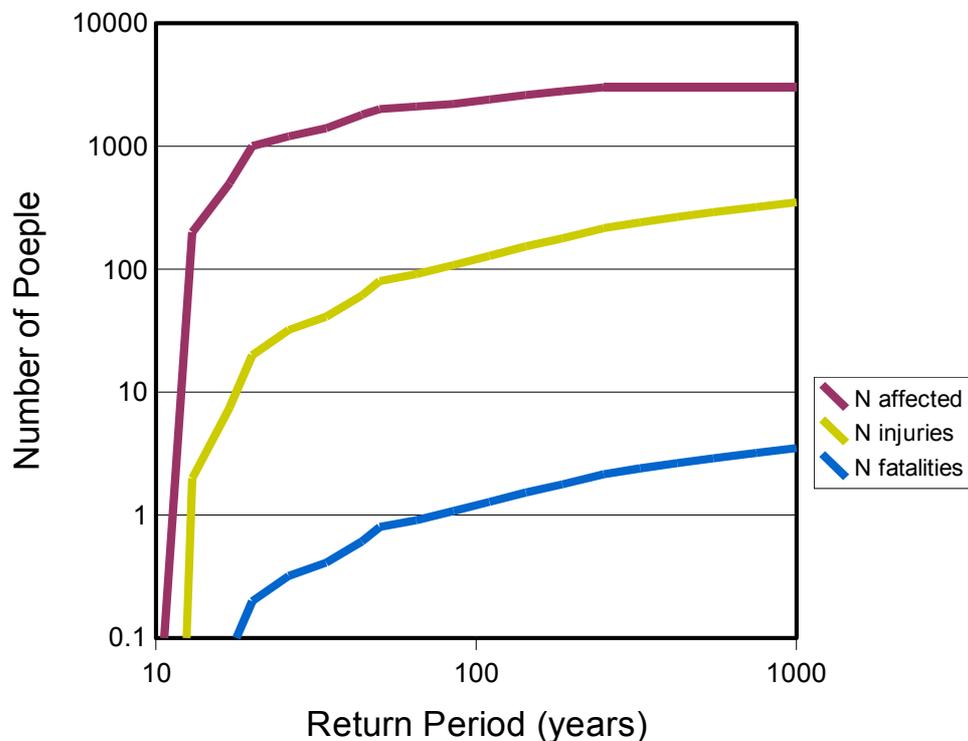
Location	No. of deaths	Distance from breach	Comments
Grimsby & Cleethorpes	none		Railway embankment collapsed and 1000 people made homeless. 6pm therefore dark Extensive promenades??
Mablethorpe & Sutton on Sea	43 (on Lincs coast)	Possibly fairly close – 200m?	Mountainous waves broke through concrete defences and embankments. One breach at Sutton was third of a mile long. Torrent of water flowing down Mablethorpe High Street was so powerful that it created a bow wave where it struck corners of buildings (high velocity!!)
King's Lynn	15	Possibly within 200m of defences?	Water rose so quickly that 15 people drowned. 1500 evacuated. In 1998 a higher tide than '53 flooded the town with no deaths (Flood warnings in force)
Hunstanton & Heacham	30	Generally within 100m of defences	Mostly in bungalows at South beach
Wells next the Sea	none		Wells town some 1500m from the open sea
Salthouse	1	In village 500m from shingle bank defence	30 properties destroyed in the village
Sea Palling	7	Within 100m of breach in dunes	Damage only behind the breach in the sand dunes and localised although houses in path of water destroyed
Gt Yarmouth	9	All within 200 m of defences	10pm (no warning). Water spilled into Town from the harbour and from Breydon Water at the back of the town.
Felixstowe	41	Within 200m of defences	Single storey prefabs swept away. Many climbed onto roofs but fell off or died from exposure.
Harwich (Old Town)	8	Within 200m of defences	1000 made homeless
Jaywick	37	Within 100m of defences	Most people had gone to bed (10pm). Most of the houses were retirement and holiday bungalows just inside the sea wall. Mainly elderly people drowned.
Canvey	58	Within 200 - 300m of defences?	Population of 11,000. Every house evacuated. Mainly bungalows.
Kent	c50		Not known but further detail may be available from Olly Grant (EA Southern)
<b>Total</b>	<b>c300</b>		
Fens 1947 Fluvial (for comparison)	none		250km <sup>2</sup> flooded. Hundreds made homeless. Some houses demolished by floodwater.

## Appendix F

### Derivation of individual risk

#### F.1 Outline of example

The precise calculation of individual risk is complex and this Appendix illustrates some of the issues involved. Consider a village bordering a river which is unaffected by flood events up to those with a 10 year return period. For an event with a 20-year return period, the number of people affected is 800 which increases to 1,800 and 3,000 for 50 and 250 year events respectively. The associated numbers of injuries (and fatalities) increase steadily with the severity of the flood event. Although, in this example, the whole village population (of 3,000) is affected by the 250 year event, the numbers of injuries and fatalities continue to rise for the more severe (and more remote) events. These (hypothetical) variations by severity of flood event are shown in Figure F.1.



**Figure F.1** Variation in numbers of people affected, injured and fatally injured by severity of flood event.

For the purposes of this illustrative example, consider three zones (A, B and C) which contain 800, 1000 and 1,200 people respectively. The full extent of each zone is affected by floods with return periods of 20, 50 and 250 years respectively. The associated numbers of injuries in each zone for each event are summarised in Table F.1.

**Table F.1 Numbers of people affected and injured by flood events**

Return period	N affected in Zone			N injuries in Zone		
	A	B	C	A	B	C
10 yrs	0	0	0	0	0	0
20 yrs	800	0	0	16	0	0
50 yrs	800	1000	0	40	30	0
250 yrs	800	1000	1200	80	70	54

**F.2 Theoretical derivation of individual risk**

In theory, in order to calculate (or estimate) the average individual risk within each zone, it is necessary to first consider the whole spectrum of flood events. A fuller picture of the events summarised in Table F.1 may appear as that shown in Table F.2.

**Table F.2 Fuller picture of numbers of people affected and injured by flood events**

Return period	N affected in Zone			N injuries in Zone		
	A	B	C	A	B	C
<b>10 yrs</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
13 yrs	200	0	0	2	0	0
17 yrs	500	0	0	7.5	0	0
<b>20 yrs</b>	<b>800</b>	<b>0</b>	<b>0</b>	<b>16</b>	<b>0</b>	<b>0</b>
26 yrs	800	200	0	24	2	0
34 yrs	800	400	0	28	6	0
44 yrs	800	800	0	36	16	0
<b>50 yrs</b>	<b>800</b>	<b>1000</b>	<b>0</b>	<b>40</b>	<b>30</b>	<b>0</b>
65 yrs	800	1000	100	44	35	1
85 yrs	800	1000	200	48	45	3
110 yrs	800	1000	400	56	50	8
143 yrs	800	1000	600	64	55	18
186 yrs	800	1000	900	72	60	31.5
<b>250 yrs</b>	<b>800</b>	<b>1000</b>	<b>1200</b>	<b>80</b>	<b>70</b>	<b>54</b>
325 yrs	800	1000	1200	88	80	60
425 yrs	800	1000	1200	96	90	66
550 yrs	800	1000	1200	104	100	72
750 yrs	800	1000	1200	112	110	84
1000 yrs	800	1000	1200	120	120	96

Table F.2 suggests that for flood events with return periods of 26-34 years, 800 and 200-400 people would be affected in Zones A and B respectively. The associated numbers of injuries would be 24-28 and 2-6 in Zones A and B respectively.

The likelihood of such events,  $df$ , is the difference between the likelihoods ( $f$ ) associated with return periods of 26 and 34 years. In other words, the likelihood of an event which would result in 24-28 and 2-6 injuries in Zones A and B respectively would be:

$$df = (1/26) - (1/34) = 0.038 - 0.029 = 0.009 \text{ per year}$$

The associated consequences of such events within Zone A can be estimated by taking the average numbers of injuries ( $N_{inj} = 26$ ) and the average number of people affected ( $N_{aff} = 800$ ). The associated contribution to the individual risk of receiving an injury,  $IR_{inj}$ , can then be derived using the expression:

$$IR_{inj} = df \times (N_{inj}) / (N_{aff})$$

For Zone A, this expression would appear as:

$$IR_{inj} (\text{Zone A}) = 0.009 \times \{0.5 \times (24 + 28)\} / \{0.5 \times (800 + 800)\} = 0.009 \times 0.0325$$

and, for Zone B:

$$IR_{inj} (\text{zone B}) = 0.009 \times \{0.5 \times (2 + 6)\} / \{0.5 \times (200 + 400)\} = 0.009 \times 0.0133$$

These estimates are based on arithmetic means of the numbers of people affected and injured. Use of geometric means would result in marginally lower answers of 0.0324df and 0.0122df.

The overall individual risk in each zone can be calculated (with reasonable precision) by summing the individual contributions across all the flood events listed in Table F.2 as shown in Table F.3. Furthermore, the total numbers of injuries can be calculated by summing the expression  $df \times N_{inj}$  as shown in Table F.3.

**Table F.3 Theoretical derivation of risk values**

Return period	f, per year	Incr. f df	N injuries/year in Zone (= df x $N_{inj}$ )			IR contribution in Zone (= df x $N_{inj}/N_{aff}$ )		
			A	B	C	A	B	C
<b>10 yrs</b>	<b><math>1.0 \times 10^{-1}</math></b>		<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
13 yrs	$7.7 \times 10^{-2}$	$2.3 \times 10^{-2}$	$2.3 \times 10^{-2}$	0	0	$2.3 \times 10^{-4}$	0	0
17 yrs	$5.9 \times 10^{-2}$	$1.8 \times 10^{-2}$	$8.6 \times 10^{-2}$	0	0	$2.5 \times 10^{-4}$	0	0
<b>20 yrs</b>	<b><math>5.0 \times 10^{-2}</math></b>	<b><math>8.8 \times 10^{-3}</math></b>	<b><math>1.0 \times 10^{-1}</math></b>	<b>0</b>	<b>0</b>	<b><math>1.6 \times 10^{-4}</math></b>	<b>0</b>	<b>0</b>
26 yrs	$3.8 \times 10^{-2}$	$1.2 \times 10^{-2}$	$2.3 \times 10^{-1}$	$1.2 \times 10^{-2}$	0	$2.9 \times 10^{-4}$	$1.2 \times 10^{-4}$	0
34 yrs	$2.9 \times 10^{-2}$	$9.0 \times 10^{-3}$	$2.4 \times 10^{-1}$	$3.6 \times 10^{-2}$	0	$2.9 \times 10^{-4}$	$1.2 \times 10^{-4}$	0
44 yrs	$2.3 \times 10^{-2}$	$6.7 \times 10^{-3}$	$2.1 \times 10^{-1}$	$7.4 \times 10^{-2}$	0	$2.7 \times 10^{-4}$	$1.2 \times 10^{-4}$	0
<b>50 yrs</b>	<b><math>2.0 \times 10^{-2}</math></b>	<b><math>2.7 \times 10^{-3}</math></b>	<b><math>1.0 \times 10^{-1}</math></b>	<b><math>6.3 \times 10^{-2}</math></b>	<b>0</b>	<b><math>1.3 \times 10^{-4}</math></b>	<b><math>7.0 \times 10^{-5}</math></b>	<b>0</b>
65 yrs	$1.5 \times 10^{-2}$	$4.6 \times 10^{-3}$	$1.9 \times 10^{-1}$	$1.5 \times 10^{-1}$	$2.3 \times 10^{-3}$	$2.4 \times 10^{-4}$	$1.5 \times 10^{-4}$	$4.6 \times 10^{-5}$
85 yrs	$1.2 \times 10^{-2}$	$3.6 \times 10^{-3}$	$1.7 \times 10^{-1}$	$1.4 \times 10^{-1}$	$7.2 \times 10^{-3}$	$2.1 \times 10^{-4}$	$1.4 \times 10^{-4}$	$4.8 \times 10^{-5}$
110 yrs	$9.1 \times 10^{-3}$	$2.7 \times 10^{-3}$	$1.4 \times 10^{-1}$	$1.3 \times 10^{-1}$	$1.5 \times 10^{-2}$	$1.7 \times 10^{-4}$	$1.3 \times 10^{-4}$	$4.9 \times 10^{-5}$
143 yrs	$7.0 \times 10^{-3}$	$2.1 \times 10^{-3}$	$1.3 \times 10^{-1}$	$1.1 \times 10^{-1}$	$2.7 \times 10^{-2}$	$1.6 \times 10^{-4}$	$1.1 \times 10^{-4}$	$5.5 \times 10^{-5}$
186 yrs	$5.4 \times 10^{-3}$	$1.6 \times 10^{-3}$	$1.1 \times 10^{-1}$	$9.3 \times 10^{-2}$	$4.0 \times 10^{-2}$	$1.4 \times 10^{-4}$	$9.3 \times 10^{-5}$	$5.3 \times 10^{-5}$
<b>250 yrs</b>	<b><math>4.0 \times 10^{-3}</math></b>	<b><math>1.4 \times 10^{-3}</math></b>	<b><math>1.0 \times 10^{-1}</math></b>	<b><math>8.9 \times 10^{-2}</math></b>	<b><math>5.9 \times 10^{-2}</math></b>	<b><math>1.3 \times 10^{-4}</math></b>	<b><math>8.9 \times 10^{-5}</math></b>	<b><math>5.6 \times 10^{-5}</math></b>
325 yrs	$3.1 \times 10^{-3}$	$9.2 \times 10^{-4}$	$7.8 \times 10^{-2}$	$6.9 \times 10^{-2}$	$5.3 \times 10^{-2}$	$9.7 \times 10^{-5}$	$6.9 \times 10^{-5}$	$4.4 \times 10^{-5}$
425 yrs	$2.4 \times 10^{-3}$	$7.2 \times 10^{-4}$	$6.7 \times 10^{-2}$	$6.2 \times 10^{-2}$	$4.6 \times 10^{-2}$	$8.3 \times 10^{-5}$	$6.2 \times 10^{-5}$	$3.8 \times 10^{-5}$
550 yrs	$1.8 \times 10^{-3}$	$5.3 \times 10^{-4}$	$5.3 \times 10^{-2}$	$5.1 \times 10^{-2}$	$3.7 \times 10^{-2}$	$6.7 \times 10^{-5}$	$5.1 \times 10^{-5}$	$3.1 \times 10^{-5}$
750 yrs	$1.3 \times 10^{-3}$	$4.8 \times 10^{-4}$	$5.2 \times 10^{-2}$	$5.1 \times 10^{-2}$	$3.8 \times 10^{-2}$	$6.5 \times 10^{-5}$	$5.1 \times 10^{-5}$	$3.2 \times 10^{-5}$
1000yrs	$1.0 \times 10^{-3}$	$3.3 \times 10^{-4}$	$3.9 \times 10^{-2}$	$3.8 \times 10^{-2}$	$3.0 \times 10^{-2}$	$4.8 \times 10^{-5}$	$3.8 \times 10^{-5}$	$2.5 \times 10^{-5}$
Totals (injuries)			2.1	1.2	0.35	$3.0 \times 10^{-3}$	$1.4 \times 10^{-3}$	$4.8 \times 10^{-4}$
<b>Totals (fatalities @1%)</b>			<b><math>2.1 \times 10^{-2}</math></b>	<b><math>1.2 \times 10^{-2}</math></b>	<b><math>3.5 \times 10^{-3}</math></b>	<b><math>3.0 \times 10^{-5}</math></b>	<b><math>1.4 \times 10^{-5}</math></b>	<b><math>4.8 \times 10^{-6}</math></b>

The overall results suggest a total of  $(2.1 + 1.2 + 0.3) = 3.6$  injuries per year (on average) and an individual risk of becoming injured ranging from  $4.8 \times 10^{-4}$  (Zone C) to  $3.0 \times 10^{-3}$  (Zone A) per year. Assuming an overall fatality rate of 1%, these figures equate to a statistical loss of life of 0.036 per year (i.e. 1 life every 27 years) and an individual risk of becoming a fatality ranging from  $4.8 \times 10^{-6}$  (Zone C) to  $3.0 \times 10^{-5}$  (Zone A) per year.

### F.3 Derivation of individual risk in practice

In practice, it is likely that data will only be collected for a few key events (as shown in Table F.1). Such data can be used to provide an estimate of the overall loss of life and associated levels of individual risk (using the same methodology as above) as shown in Table F.4.

**Table F.4 Derivation of risk values in practice**

Return period	f, per year	Incr. f df	N injuries/year in Zone (= df x N <sub>inj</sub> )			IR contribution in Zone (= df x N <sub>inj</sub> /N <sub>aff</sub> )		
			A	B	C	A	B	C
10 yrs	$1.0 \times 10^{-1}$		0	0	0	0	0	0
20 yrs	$5.0 \times 10^{-2}$	$5.0 \times 10^{-2}$	$4.0 \times 10^{-1}$	0	0	$1.0 \times 10^{-3}$	0	0
50 yrs	$2.0 \times 10^{-2}$	$3.0 \times 10^{-2}$	$8.4 \times 10^{-1}$	$4.5 \times 10^{-1}$	0	$1.1 \times 10^{-3}$	$9.0 \times 10^{-4}$	0
250 yrs	$4.0 \times 10^{-3}$	$1.6 \times 10^{-2}$	$9.6 \times 10^{-1}$	$6.4 \times 10^{-1}$	$4.3 \times 10^{-1}$	$1.2 \times 10^{-3}$	$8.0 \times 10^{-4}$	$7.2 \times 10^{-4}$
Totals (injuries)			2.2	1.1	0.43	$3.3 \times 10^{-3}$	$1.7 \times 10^{-3}$	$7.2 \times 10^{-4}$
<b>Totals (fatalities @1%)</b>			<b><math>2.2 \times 10^{-2}</math></b>	<b><math>1.1 \times 10^{-2}</math></b>	<b><math>4.3 \times 10^{-3}</math></b>	<b><math>3.3 \times 10^{-5}</math></b>	<b><math>1.7 \times 10^{-5}</math></b>	<b><math>7.2 \times 10^{-6}</math></b>
<i>Totals (from Table F.3)</i>			<i><math>2.1 \times 10^{-2}</math></i>	<i><math>1.2 \times 10^{-2}</math></i>	<i><math>3.5 \times 10^{-3}</math></i>	<i><math>3.0 \times 10^{-5}</math></i>	<i><math>1.4 \times 10^{-5}</math></i>	<i><math>4.8 \times 10^{-6}</math></i>

As can be seen from comparing the last two rows of Table F.4, the ‘simple’ method using data from three flood events (as well as the threshold event) provides a slight underestimate of the associated risks. The estimated number of injuries per year (on average) is estimated as 3.9 (cf 3.6 in Table F.3).

As such, it is considered that this simple method is sufficiently robust to be carried forward with the methodology for further work in Phase 2.