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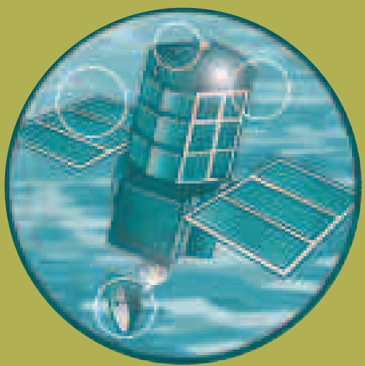
Flood and Coastal Defence R&D Programme

Flood Risks to People

Phase 2

FD2321/TR1

The Flood Risks to People Methodology



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R&D OUTPUTS: FLOOD RISKS TO PEOPLE

Phase 2

FD2321/TR1 The Flood Risks to People Methodology

March 2006

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Statement of use
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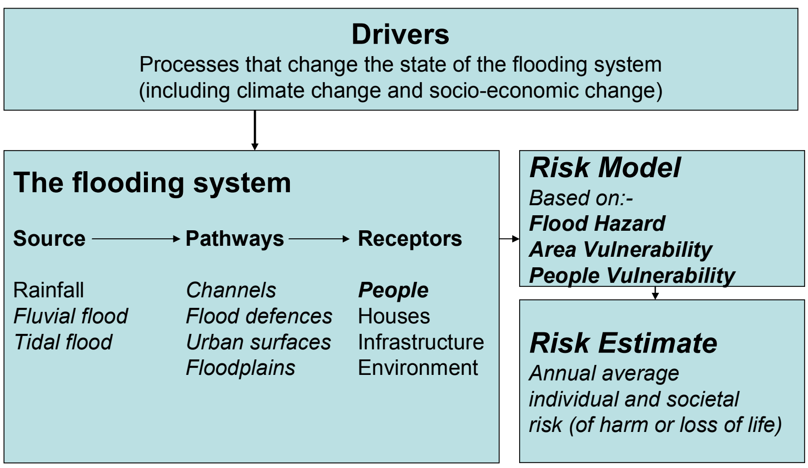
EXECUTIVE SUMMARY

Flooding from rivers, estuaries and the sea poses a risk to people as well as causing significant economic impacts. In the last decade of the 20th century floods accounted for 12% of all deaths from natural disasters, claiming about 93000 lives across the world (OECD International Disasters Database). In 1953 the North Sea floods caused approximately 2500 deaths across the UK, Netherlands, Belgium and Germany and concentrations of fatalities have been associated with flash floods such as Lynmouth in Cornwall (1952, over 30 deaths) and Vaison-la-Romaine in France (1992, 38 deaths). In the UK, there were a small number of fatalities associated with the Easter 1998 and Autumn 2000 floods. In August 2004, a major airborne rescue operation was required to rescue victims of the Boscastle flood and in January 2005, the media reported 3 fatalities in flooding in Carlisle.

> A key Government objective for the Environment Agency is *"to reduce the risks to people and to the developed and natural environment from flooding."*
>
> Environment Agency indicator: *"No loss of life attributable to flooding in areas receiving a full flood warning service."*
>
> Environment Agency Corporate Strategy, 2002-07.

Flood forecasting and warning, emergency planning, land use planning and the operation of flood defence systems have all contributed to reducing risks in the UK. However, flood risks cannot be completely eliminated and to support Government targets for flood risk management there is a requirement for methods to estimate the risks to people, as well as risks of economic and environmental damage. As shown in Figure ES1 the project is focused on people and provides measures of annual average risk that can be used alongside annual average economic damage and other social and environmental criteria to improve flood risk management.

Figure ES1. The Risks to People project in the context of the source-pathway-receptor model of flood risk.



The “Risks to People Phase 2” method is a form of multi-criteria assessment based on the concepts of flood hazard, area vulnerability and people vulnerability. The method was tested using seven case studies including the flooding in Carlisle in 2005. These examples demonstrated that the method works well, providing sensible estimates of the fatalities and injuries for a range of different fluvial and tidal flood events.

Improving flood risk management

The research has a wide range of potential applications from raising awareness of the dangers of flood water, targeting flood warning, emergency planning, development control and flood mapping. The approaches developed can make use of information from other projects, such as the National Flood Risks Assessment (NaFRA) and be incorporated into the overall Risk Assessment for Strategic Planning (RASP) framework as well supporting Catchment Flood Management Plans and more local initiatives to understand manage flood risks.

This report (FD2321/TR1) describes the Risks to People Methodology that is based on a multi-criteria assessment of factors that affect Flood Hazard, the chance of people in the floodplain being exposed to the hazard (Area Vulnerability) and ability of those affected to respond effectively to flooding (People Vulnerability). The report describes the key concepts, provides an overview of how the method was developed and shows a number of example applications.

A second Technical Report (FD2321/TR2) is a guidance document that explains how the overall method or its component parts can be applied in flood risk management for land use planning, the management of flood defences, measures for responding to flooding and finally, in ongoing and new research projects. The outputs of consultation, workshops and background research are included in the Project Record (FD2321/PR).

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

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

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

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1. INTRODUCTION

Flood Risks to People Phase 2 (FD2321) covers death or serious harm to people that occurs as a direct result of the flood either during or up to one week after the event. The research examines the causes of death or serious harm from flooding and develops a methodology for assessing flood risks to people. The methodology is applicable to the UK and can be used to assess flood risks to people at a range of scales and levels of detail. The methodology includes a mapping element that uses Geographical Information Systems (GIS) to analyse, manage and communicate flood risks to people.

This report presents the final methodology for the project. The method was developed as a result of research carried out in two Phases. Phase 1 of the project developed a method for combining information of flood hazard with criteria related to the vulnerability of areas and people to flooding for estimating the likelihood of serious injury or death from flooding. Phase 1 tested the methodology on three historical case studies showing that it was both practical and effective at estimating numbers affected by extreme flood events (HR Wallingford, 2003). Phase 2 of the research completed more detailed investigations into flood hazard and flood vulnerability and reported interim conclusions at various stages of the research (HR Wallingford, 2004a, 2004b and 2004c). During this phase a number of changes were made to the Flood Hazard, Area Vulnerability and People Vulnerability aspects of the Risks to People methodology. This report presents the final methodology and should be considered the best practice for assessing the risks to people from flooding.

In addition to this technical report on the Flood Risks to People Methodology, the other Phase 2 final outputs are:

- Project Record (FD2321/PR, HR Wallingford, 2005a), which collates all of the information presented in the inception report and interim reports.
- Guidance Document (FD2321/TR2, HR Wallingford, 2005b), which provides guidance on development control and flood risk management and includes a summary for researchers which explains the links of this project with other EA/DEFRA R&D and which identifies areas for further research.

Sections 2 to 5 of this report outline the final methodology and Sections 6 and 7 explain how it can be applied, with some case studies and mapping examples.

2. OVERVIEW OF METHODOLOGY DEVELOPMENT

2.1 Phase 1 Methodology

As reported in the Phase 1 Report (HR Wallingford, 2003), the proposed methodology was based on the following equation (as applied to a particular flood):

Ninj = Nz x Hazard Rating x Area Vulnerability x People Vulnerability

where,	Ninj =	number of injuries within a particular hazard ‘zone’;
	Nz =	number of people within the hazard zone (at ground/basement level);
	Flood Hazard Rating =	function of flood depth/velocity (within the hazard zone being considered) and debris factor;
	Area Vulnerability =	function of effectiveness of flood warning, speed of onset of flooding and nature of area (including types of buildings); and
	People Vulnerability =	function of presence of people who are very old and/or infirm/disabled/long-term sick

Furthermore the number of fatalities (in a particular flood) was taken to be a function of the number of injuries and the hazard rating. In other words, the more severe the flood (in terms of flood depth and/or velocity), the greater the proportion of fatalities amongst those injured.

The Risks to People methodology is based on applying the above calculations to a number of hazard zones and flood events in order to build up an overall picture of the associated level of risk in particular geographical areas.

2.2 Consultation

There is little doubt that this R&D Project is of great interest to a wide range of people and organisations involved in flood and coastal risk management. To ensure that the views of these stakeholders were identified, there has been extensive consultation during both Phases 1 and 2 of the Project. One of the key objectives of the consultation was to ensure that the outputs from the project met the wishes of stakeholders.

Outputs from the Risks to People project meet the majority of wishes expressed by those consulted. There are some areas that the project was unable to address within its scope. These issues have either been taken forward in parallel Environment Agency research projects, e.g. FD2308 on Flood Risk Guidance for New Developments, or recommended as items for ongoing Environment Agency and Defra research (see Guidance Document). Table 2.1 summarises the requirements of stakeholders based on a consultation meeting held on 23 September 2004 together with a commentary on the degree to which the particular items could be met by the outputs from this project. It should be noted that many of these items had been raised in previous discussions with stakeholders.

Table 2.1: Stakeholder 'Wish List' and Associated Commentary

Function	Stakeholder Wishes	Comment
Project appraisal	A method for estimating flood risks to people for Multi-Criteria Analysis (MCA). The MCA approach should link with the Risks to People outputs.	The method developed for estimating risks to people is, essentially, an MCA method (as it is based on scoring and combining attributes). It is suggested that the 'risks to people' methodology should feed into an overall MCA methodology for project appraisal.
Flood mapping	Methods that can be used to calculate the following for national mapping purposes: • Flood hazard • Vulnerability • Flood risks to people (if required)	This is the prime output from the project - a methodology that can be incorporated into 'high level' mapping. Clearly it would be possible to map the 'risks' or component parts (such as 'hazard', 'area vulnerability' or 'people vulnerability') each of which may have specific applications outside the overarching 'risks to people' methodology.
Flood warning	a) Methods that can be used to calculate flood hazard and vulnerability for local application. b) Guidance on identifying areas of high flood risks to people is needed for Agency flood warning plans. c) Guidance arising from the project on what to do and what not to do during a flood.	a) The methodology is designed for 'high level' mapping. As such, it is intended that risks can be determined from consideration of 'area' characteristics (for example, by postcode or national census "Output Areas' ~ ca. 120 houses). b) It is intended that the 'high level' mapping resulting from the application of the methodology presented in this report will identify areas of high flood risks to people. c) During the course of the project, a number of relevant items have been identified (for example, 'safe' flood depths for vehicles) and these are reported on this report and in the associated Guidance Document. It is to be hoped that such information will be taken forward by the relevant authorities for guidance to staff and members of the public as appropriate.
Emergency planning and response	a) Methods that can be used to calculate flood hazard and vulnerability for local application. b) Guidance on identifying areas of high flood risks to people is needed for Local Authority emergency plans. Guidance should be based on local data where possible.	a) As for 'flood warning - a)' above. b) As for 'flood warning - a) and b)' above
Flood awareness	Guidance arising from the project on what to do and what not to do during a flood.	As for 'flood warning - c)' above.

Function	Stakeholder Wishes	Comment
Flood defence regulation and development control	a) Method for calculating flood hazard information for development control and planning.	a) Since the level of flood risk to people can be determined at an area level, these outputs would be suitable for consideration in developing strategic plans. However, they may not be appropriate for consideration in respect of planning applications for small individual developments - as the 'true' risk will be dependent on a range of site-specific factors. It would be hoped that such factors would be considered in the site-specific flood risk assessment prepared in accordance with PPG25. The examples in Appendix * show how the methodology could be used to determine the number of houses permitted within flood zones based on the concept of "Acceptable Risk."
	b) Method for assessing flood risks behind defences, which could be used by the Agency to develop guidance.	b) The methodology has been developed to consider those at risk with and without defences.
	c) Guidance on flood risks to people to help the Agency develop tools and other information that can be used to influence planners.	c) As for a) above.
	d) Guidance on the acceptability of risk is desirable but the Agency excluded this item from the original Terms of Reference.	d) This was not considered in Phase 2 of the project but parallel work completed by the project team is included in the appendices.
	e) A method that identifies the influence of mitigation measures (flood warning, development control) so that the benefits of these measures can be identified.	e) The methodology can be used to demonstrate the risks 'before' and 'after' particular improvements. As such, it is possible to demonstrate the 'benefits' (in terms of reduced risk) associated with mitigation measures.
Land use planning	Flood hazard information for development control and planning.	As for 'flood defence - a)' above.
Flood Plans for reservoirs	Methods for calculating flood hazard, vulnerability and flood risks to people for inclusion in the specification for reservoir Flood Plans.	It should be possible for those involved in developing reservoir 'flood plans' to adopt/ adapt the methodology presented in this report.

2.3 Responsibilities for Flood Risk Management

As illustrated in Table 2.1, flood risks to people are considered across a wide range of functions. Furthermore, these functions are the responsibility of a range of authorities. Clearly, planners have a responsibility for planning and the Environment Agency has a key role in the provision of flood warning services and flood defences. HR Wallingford (2004b), sections 4.2 and 4.3 provide an overview of the responsibilities of the various authorities.

2.4 Structure of the report

The following sections describe the concepts of Flood Hazard, Area Vulnerability and People Vulnerability individually, and then describe how these components are combined to estimate the individual and societal risks of serious harm during a flood event.

The Flood Hazard, Area Vulnerability and People Vulnerability sections are structured as follows:-

- The starting point is the Phase 1 formulae as reported in HR Wallingford (2003).
- Changes made to each formula in Phase 2 are described.
- The final formula is presented at the end of each section.

A synopsis and example of the final methodology is described in Section 6.

3. FLOOD HAZARD RATING

3.1 Introduction

There is a broad consensus that the degree of hazard that floodwaters present to people (and to vehicles and property) is a function of both velocity and depth. There are a number of other physical characteristics that may affect the stability of people during flooding, such as water temperature, the presence of “slip” and “trip” hazards such as “blown” man-hole covers and the presence of debris. The presence of debris was included in Phase 1 as a “debris factor” in the flood hazard equation. This was retained in the final flood hazard formula.

3.2 The Phase 1 flood hazard formula

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

$$HR = d \times (v + 1.5) + DF$$

where,

HR = (flood) hazard rating;

d = depth of flooding (m);

v = velocity of floodwaters (m/sec); and

DF = debris factor (= 0, 1, 2 depending on probability that debris will lead to a significantly greater hazard)

During the course of Phase 2 of this project, this equation has been subject to further review to examine whether it provides a robust reflection of the degree of hazard posed by floodwaters.

3.3 Depth and Velocity Functions

3.3.1 Overview

Leaving aside the issue the debris (which is considered further below), flood hazard is a function of both depth and velocity. A number of alternative flood hazard formulae were considered with reference to experimental data and in the context of the overall Risks to People Methodology. (A discussion of the pros and cons of the alternative equations and the experimental evidence is included in Appendix 1).

The limited amount of published research on the direct effects of floodwater on people tends to focus on the velocity/depth required to knock people off their feet. Clearly, this, in turn, depends on the characteristics of the subjects (particularly height and mass).

Experimental work from Abt (1989) and RESCDAM (2000) was reviewed. Figure 3-1 plots the results from these two experiments with (a) and indication of the typical height times mass for different ages based on UK Department of Health figures and (b) some thresholds indicating the relative hazard associated with different depth-velocity combinations.

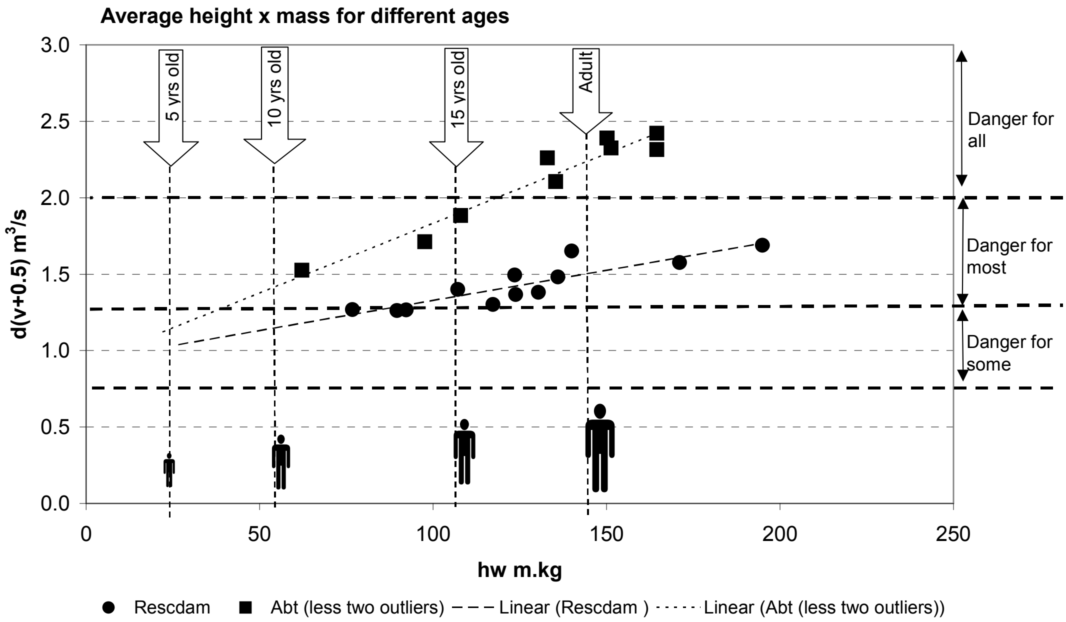

Figure 3.1: The interpretation of the data sets to derive flood hazard thresholds

The following expression was found to be reliable for determining the threshold for losing stability:

$$d \times (v + 0.5) = a \times hw + b$$

where,

d = depth of flooding (m);

v = velocity of floodwaters (m/sec);

hw = height (m) x weight (kg) of subject; and

a, b = constants.

Further details are provided in Appendix 1, HR Wallingford *et at* (2004b) section 3 and HR Wallingford (2004c) section 2.

3.3.2 Choice of flood hazard classes.

In the risks to people calculation flood hazard is used as a variable that affects the proportion of exposed people that are injured or killed. However, classification of flood hazard is required for flood hazard mapping and the development of guidance. Given the difference between the two main experiments and the fact that these cannot reproduce real flood conditions, it is appropriate to be precautionary in setting and describing hazard classes so that these are communicated effectively to those at risk.

The characterisation shown in Table 3.2 is proposed.

Table 3.2: Hazard to People as a Function of Velocity and Depth

d x (v + 0.5)	Degree of Flood Hazard	Description
<0.75	Low	Caution *"Flood zone with shallow flowing water or deep standing water"*
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) *"Danger: Flood zone with deep or fast flowing water"*
1.25 - 2.5	Significant	Dangerous for most people *"Danger: flood zone with deep fast flowing water"*
>2.5	Extreme	Dangerous for all *"Extreme danger: flood zone with deep fast flowing water"*

Such categorisation could be useful for a range of applications including:-

- Planning of safe access and exit for new developments
- Emergency planning advice for people at risk and the emergency services
- Development of household or community flood plans

Figure 3-2 provides a look-up table of flood hazard classes for different velocities and depths. The use of flood hazard classes is described in the Guidance Document.

Velocity Coefficient C	**0.5**										
(V+C) * D	**Depth**										
Velocity		**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**
	0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25
	0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
	1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
	2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
	2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
	3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
	3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
	4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
	4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
	5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75

	From	To	
Class 1	0.75	1.25	Danger for some
Class 2	1.25	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

Figure 3.2: Velocity, depth and flood hazard matrix

3.3.3 Flood Damage to Buildings

In broad terms, buildings are more resilient to floodwaters than people. Extensive research into this area has been undertaken by CURBE (see, for example, Kelman 2002). Further detail is provided in HR Wallingford *et at* (2004b) section 3 and HR Wallingford *et at* (2004c) section 2, but, as for people, the severity of damage is a function of both depth and velocity.

The direct damage of floodwater to buildings and the potential risks to people related to building collapse is not included in the risks to people methodology. With the one recent exception of Boscastle, there is not substantial evidence of buildings collapsing during floods in the UK. Nevertheless, understanding the potential impacts of flood water on building structure is still an important area for research; further commentary is provided in Appendix 1 and building resilience is included in the Guidance Document.

3.3.4 Flood Damage to Vehicles

There are, essentially, three reasons why vehicles cannot be used in floodwaters:

- the presence of water stops the engine functioning;
- the vehicle floats; and
- the vehicle becomes difficult to control.

Cars will stop and/or float in relatively shallow water (as low as 0.5m in depth) while emergency vehicles may survive in slightly deeper waters (up to 1m in depth). However, with suitable modifications (high level air intakes/exhausts), a fire engine remains controllable in depths of 0.5m at up to 5 m/sec water flows.

These findings are discussed in more detail in HR Wallingford *et at* (2004b) section 3 and HR Wallingford *et at* (2004c) section 2. As in the case of buildings, the Phase 1 methodology was not modified to specifically account for vehicles. Rather, these aspects have been incorporated into the associated Guidance Document.

3.4 Debris Factor

In the original Phase 1 methodology, a debris factor (DF) was added to the depth/velocity function. The value of DF was taken to be 0, 1, 2 depending on the probability that debris would lead to a significantly greater hazard. Although there are few reliable data on the importance of such a factor, the values will need to be reduced (and values of 0, 0.5, 1 are suggested) to reflect the change in the depth/velocity function.

Table 3.1: Guidance on debris factors for different flood depths, velocities and dominant land uses

Depths	Pasture/Arable	Woodland	Urban
0 to 0.25 m	0	0	0
0.25 to 0.75 m	0	0.5	1
d>0.75 m and\or v>2	0.5	1	1

3.5 Final flood risks to people method: Hazard rating formula

The revised 'hazard rating' expression based, primarily, on consideration to the direct risks of people exposed to floodwaters is:

$$HR = d \times (v + 0.5) + DF$$

where,
HR = (flood) hazard rating;
d = depth of flooding (m);
v = velocity of floodwaters (m/sec); and
DF = debris factor (= 0, 0.5, 1 depending on probability that debris will lead to a significantly greater hazard)

4. AREA VULNERABILITY

4.1 Introduction

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

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

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

- flood warning;
- speed of onset; and
- nature of area.

Each of the factors was scored on a simple 1, 2, 3 scale as shown in Table 4.1

Table 4.1: Area Vulnerability (Phase 1 Methodology)

Parameter	1 - Low risk area	2 - Medium risk area	3 - High risk area
Flood warning	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	Multi-storey apartments	Typical residential area (2-storey homes); commercial and industrial properties	Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc.

4.2 Flood Warning

Flood warning is an important part of the Environment Agency's work on flood risk management. The Agency's policies and associated objectives are described in more detail in HR Wallingford. (2004b) section 4.4.

Clearly, the effectiveness of flood warning not only relies on providing a timely warning but also for recipients of the warning to take effective action. The Agency has three key targets that are identified in relation to flood warning:

- to increase the coverage of flood warning services to 80% of properties in flood risk areas by 2010 (Agency Corporate Plan (2002-06))[1];
- prior warning will be provided (two hours in general) to people living in designated flood risk areas where a flood forecasting facility exists and where lead times enable the Agency to do so (Agency's Customer Charter)[2]; and
- to ensure that 75% of residents in flood risk areas will take effective action by 2007 (Agency's Corporate Strategy).

Progress towards these targets are reported on by (most) Agency regions. Table 4.2 below presents the relevant data, where available.

Table 4.2: Progress towards Flood Warning Targets

Agency Region	% of at risk properties covered by flood warning system[1]	% of warnings meeting two hour target[2]	% of people taking effective action[3]
Anglian	55	75	*36*
Midlands			
- East	13	54	*36*
- West	27	54	*36*
North East			
- Yorkshire & Humber	75	88	*36*
- North East	53	88	*36*
North West	65	0	*36*
Southern	*61*	65	*36*
South West	*61*	61	*36*
Thames	*61*	65	*36*
England	**61**	**63**	**36**
Wales	45	*63*	55

NB Figures in italics are based on England figures where no other data are available

1 Based on information from State of the Environment Reports (where provided), available on Regional websites, www.environment-agency.gov.uk, the Agency's Annual Report 2002/03 and Measure 218A.

2 Environment Agency (2004): **High Level Target 2 – Provision of Flood Warnings**, Report to Defra, dated February 2004.

3 Baseline figures reported for Measures 217A and 217B. It is recognised that the 36% figure is somewhat unrealistic and variation between regions will become apparent once data for the KPI are collected.

Table 4.3 shows how the progress against these targets can be used to derive a score for flood warning.

1 It is noted that the 80% target is close to the limit of what is possible, due to flash flooding.

2 This relates to Defra's High Level Target 2 on the provision of flood warnings

4.2.1 Final flood risks to people method: Flood warning.

Each figure is calculated as a percentage of its target, e.g. for Anglian region, the percentage of at risk properties covered by a flood warning system is 55%, compared to a target of 80%, thus the 'score' is 0.69 (= 55/80). The scores across all three targets are then combined to give a flood warning score on a scale of 1 (good warning system) to 3 (no warning system), using the following expression:

$$\text{FW Score} = 3 - (P1 \times (P2 + P3))$$

where, P1 = % of Warning Coverage Target Met;
P2 = % of Warning Time Target Met; and
P3 = % of Effective Action Target Met.

Table 4.3: Calculation of Flood Warning Score

Agency Region	% of Warning Coverage Target Met (80%) = P1	% of Warning Time Target Met (100%) = P2	% of Effective Action Target Met (75%) = P3	FW Score = 3 - (P1 x (P2 +P3))
Anglian	0.69	0.75	0.48	2.15
Midlands				
- East	0.16	0.54	0.48	2.83
- West	0.34	0.54	0.48	2.66
North East				
- Yorkshire & Humber	0.94	0.88	0.48	1.73
- North East	0.66	0.88	0.48	2.10
North West	0.81	0.00	0.48	2.61
Southern	0.76	0.65	0.48	2.14
South West	0.76	0.61	0.48	2.17
Thames	0.76	0.65	0.48	2.14
England	**0.76**	**0.63**	**0.48**	**2.15**
Wales	0.56	0.63	0.73	2.23

4.3 Speed of Onset

The 'speed of onset' is clearly an important factor affecting flood vulnerability. If floodwaters rise very slowly, people will be aware and be able to react, ensuring the their own safety and the safety of others. If there is rapid flooding people have little opportunity to seek safe refuge. In the Boscastle floods of August 2004 anecdotal evidence suggested that the flood rose to its peak within 15 to 30 minutes, leaving no time for people to escape the torrent of floodwater.

In the risks to people method it is regarded as an area characteristic as it is related to flood defences and the propagation of flood water across an areas (a pathway variable) as well as the physical characteristics, such as "Time to peak" for fluvial floods (a source variable). The 'speed of onset' criteria and scores have remained the same as those reported in Phase 1.

4.3.1 Final flood risks to people method: Speed of onset.

There are three classes for the speed of onset criteria:-

- Low risk: Onset of flooding is very gradual (many hours)
- Medium risk: Onset of flooding is gradual (an hour or so)
- High risk: Rapid flooding

Examples of areas subject to very gradual flooding include groundwater flooding and fluvial flooding from large groundwater dominated catchments. Areas vulnerable to rapid flooding include small steep catchments, small clay catchments, areas behind defences and urban areas subject to sewer flooding following intense rainstorms.

4.4 Nature of Area

The “nature of the area” criteria is an important variable that can change the risks from one flood zone to another due to the presence or absence of buildings that could provide safe refuge above the maximum water level during a flood. As such it is an important variable for defining flood risk zones as described in the section on risks to people mapping (Section 7).

During the course of Phase 2, consideration has been given to the potential for the presence of sites containing hazardous materials within the floodplain to present a significant risk to people in the event of a flood.

As described in HR Wallingford (2004b) section 4.5, there are numerous facilities located within the floodplain which, in the event of a flood, could be involved in an incident which presents a hazard to those nearby. Such incidents may involve: a direct reaction between the floodwaters and the material being handled; damage to tanks (or other items of plant) leading to a release; or the floodwaters can transport hazardous materials outside their normal containment (for example, an overflowing lagoon).

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

Although ‘normal’ landfill facilities are not considered to present a risk to people nearby in the event of flooding, it is possible that hazardous waste facilities (storage, treatment and disposal) may present a risk.

However, it must be stressed that the significance of the associated risk (relative to the direct risk associated with the floodwaters) is likely to be low. This is borne out by the, generally, low numbers of injuries and fatalities associated with flooding incidents which involve hazardous materials. Therefore the presence of hazardous sites was not included in the risks to people method.

However, there will always be a low residual risk of a major incident and with these points in mind, it is recommended that consideration of the potential interaction between floodwaters and sites and/or transport routes containing hazardous materials is considered in drawing up local emergency plans and procedures.

4.4.1 Final flood risks to people method: Nature of area.

The 'nature of area' factors and scores proposed in Phase 1 were retained for the final method:-

- Low risk: Multi-storey apartments
- Medium risk: Typical residential area (2-storey homes);
- High risk: Basement properties and car parks, low rise commercial and industrial properties, bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc…

Notes:
1. In some areas there may be other specific buildings that are high risk so the above list is not prescriptive.
2. Parks and other open areas where people congregate are considered to be vulnerable areas even if their population density is low. (Note that if there a few people present in such areas the final risks to people will be very low).
3. The presence of hazardous sites should still be considered in emergency plans and procedures.

4.5 Final flood risks to people method: Expression for Area Vulnerability

The revised 'area vulnerability' score is similar to that used in the Phase 1 methodology and is summarised in Table 4.4.

Table 4.4: Area Vulnerability (Final Method)

Parameter	1 - Low risk area	2 - Medium risk area	3 - High risk area
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	Multi-storey apartments	Typical residential area (2-storey homes); commercial and industrial properties	Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc.
Flood warning	Score for flood warning = 3 - (P1 x (P2 + P3)) where P1 = % of Warning Coverage Target Met P2 = % of Warning Time Target Met P3 = % of Effective Action Target Met		
Area Vulnerability (AV) = sum of scores for 'speed of onset', 'nature of area' and 'flood warning'			

5. PEOPLE VULNERABILITY

5.1 Introduction

In the Phase 1 methodology, consideration was given to two factors which could be used to characterise the ‘vulnerability’ of people within a particular area to flooding. These two factors were:

- the presence of the very old; and
- the presence of inform/disabled/long term sick.

Each factor was scored on a simple scale as shown in Table 5.1

Table 5.1: Area Vulnerability (Phase 1 Methodology)

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)

5.2 Other Parameters

During Phase 2, consideration has been given to a wide range of socio-economic factors which could influence the vulnerability of particular groups to being injured by floodwaters. The key parameters are summarised in Table 5.2 with further detail in HR Wallingford (2004c) Appendix 2.

Table 5.2: Factors Considered for People Vulnerability

Factor	Research Indications	Commentary
The Elderly	• Epidemiological research indicates that over the age of 75 there is an increase in the incidence and severity of pre-existing health problems (Tapsell *et al*, 2002). • Thrush (2002) reports that confused elderly people may be frightened and bewildered by (informal) flood warnings. • The non-institutionalised elderly are more difficult to locate in situations requiring evacuation (Keys, 1991). • The very old are more vulnerable to the effects of immersion, such as	Factor already included in the Phase 1 methodology and should be retained based on evidence that the elderly are more vulnerable to health problems related to flooding.

Factor	Research Indications	Commentary
	shock and hypothermia (NHS Direct). In addition, the diseases that predispose people to hypothermia are more common in those aged over 65 (eMedicine, 2001).	
The Long Term Sick and Disabled	• This variable is strongly correlated with old age. • People with impaired hearing are at particular risk of not receiving telephone warnings. • On exposure to floodwater, many pre-existing medical conditions can increase the probability of death occurring, e.g. the mortality rate for hypothermia for those with pre-existing illness is higher than 50% (compared to 5% in healthy individuals).	Factor already included in Phase 1 methodology and should be retained based on evidence that pre-existing illness may predispose people to health problems related to flooding. However, a degree of double counting may occur, depending on the strength of correlation of this factor with age.
The Financially Deprived	• Poor households are less likely to own a car so may require special transport provision in the event of evacuation (Keys, 1991).	Financially deprived households may be less likely to receive a warning or to respond effectively, however there is no evidence to suggest that they are more likely to experience health problems. In addition, this factor is associated with other 'vulnerability' characteristics considered.
Single Parents and Children	• Evacuation or rapid response may be more difficult (Keys, 1991). • The very young are especially susceptible to hypothermia and shock (Grieve, 1959).	The evidence suggests that very young children are more susceptible to health problems, whether or not they are part of a single parent household. However, evacuation may be more difficult in this situation.
Language and Ethnicity	• Warnings are less likely to be received and acted upon (Drabek, 2000). • People may have difficulty understanding emergency service workers (Keys, 1991).	These factors are more related to the effectiveness of flood warnings and communication than the potential for flooding to cause health impacts.
Transient and Recent Immigrants	• Generally less likely to receive warnings than residents (Drabek, 2000).	
Leisure-related vulnerability	• Seasonal tourists may occupy hazardous regions (Cutter, 2003).	Potentially significant in some areas - see below.
The Roofless Homeless	• Many rough sleepers suffer from acute health problems (Crisis, N.D.; McMurray-Avila *et al*, 1998) making them more vulnerable to the effects of immersion.	There are no comprehensive national figures on the extent of single homelessness (Shelter, 2001) that would enable this factor to be accounted for.

5.3 Parameters Taken Forward

Based on Table 5.2, the two key parameters are the presence of the very old and the infirm/disabled/long-term sick. These two parameters account for two of the four parameters used in the Social Flood Vulnerability Index (see HR Wallingford (2004c) appendix 2). Although other components of the SFVI may be of interest when considering other aspects of flooding and flood risk management, they are not of direct relevance when considering the direct risks of injury associated with flooding.

The very old and the infirm/disable/long-term sick account for about 10% and 15% of the adult population respectively (and it is acknowledged that some people will fall into both categories). For simplicity (and to retain a degree of consistency with the Phase 1 approach), it is recommended that the 'people vulnerability' score is simply the sum of the two relevant SVFI factors:

- the percentage of all residents suffering from long-term illness; and
- the percentage of all residents aged 75 or over.

This is a pragmatic conclusion that fits with overall aims of the methodology and mapping process. For example, it is clear that children are particularly vulnerable in any type of emergency because they are physically smaller and weaker than adults and are especially susceptible to hypothermia and shock. At the scale of risks to people mapping their presence or absence will not create differentiation from one place to another. However the presence of lone parents may be a useful substitute and the use of this variable warrants further research. The accompanying Guidance Document provides further information on flood awareness and characteristic behaviour of different groups (by gender, age and so on) of people during floods.

5.4 Final flood risks to people method: People Vulnerability

The revised 'people vulnerability' score (Y expressed as a percentage) is simply:

Y = %residents suffering from long-term illness + %residents aged 75 or over.

6. DETERMINING THE RISKS TO PEOPLE

6.1 Introduction

In order to determine the annual average individual or societal risk, several flood events must be considered. The choice of scenarios is important and will have an impact on the final outputs particularly in the case of areas defended to a high standard, such as the Thames Estuary.

In order to use the full risks to people method at least 5 events should be considered. The greatest impact is likely to be for more extreme events and therefore the choice of events must include or, in a special cases, exceed the 0.1% or 1 in 1000 year flood. The area considered for typical risks to people assessment will be defined by the Environment Agency's 1000 year Extreme Flood Outline (EFO). The choice of events should cover a similar range to those outlined below:-

(a) for an undefended area with regular flooding choose the 20, 50, 100, 250, 1000 year events;
(b) for a defended area (to, say, 1 in 75) choose 100, 200, 300, 500, 1000 year events;
(c) for a highly defended area (to, say, 1 in 800) choose 1000, 1500, 2000, 4000 year events.

For heavily populated floodplains that are defended to a high standard by complex flood defence systems individual events may be caused by a combination of forcing conditions and defence failure affecting any single or multiple components of the defence system. In such cases, more events may need to be considered and this may be best achieved by using an established risk assessment framework, such as RASP.

The following hypothetical example of *"Riskville"* considers the methodology in three simple steps. In step 1, a single event occurring on an undefended floodplain is considered with flood zones defined in terms of distance from the source of flooding. In step 2 the results of a further four events are combined to illustrate the calculation of the annual average individual and societal risk. In step 3 the concept of acceptable risk is introduced.

In Section 7 and Appendix ** the methodology is applied the four examples from Phase 1 of the research project and three new examples completed by Risk & Policy Analysts as part of a research project completed for the Environment Agency. The new examples are Lewes on the River Ouse, Tripcock Point in the Thames Estuary and Hull in the Humber Estuary.

6.2 Step 1. Quantifying the relationships (exposure assessment) for a single event

The event considered in this example is the 1% flood for the town of "Riskville" that has a population of 3785 people located within the 0.1% flood outline. It currently has no flood defences.

6.2.1 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). The risks to people estimates X based on Area Vulnerability.
Y	is the proportion of those at risk who will suffer death/injury. The risks to people method calculates Y based on People Vulnerability.

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

6.2.2 Flood hazard rating

The flood hazard formula is calculated as a function of velocity, depth and the presence of debris using the formula:-

Flood hazard = (v + 0.5) x d

Table 6.1: Flood hazard zones and those at risk in Riskville, 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+0.5) + DF
0-50	25	3	2	1 – possible	8.5
50-100	50	2	1.8	1 – possible	5.6
100-250	300	1	1.3	1 – possible	2.8
250-500	1000	0.5	1.2	1 – possible	1.85
500-1000	2500	0	0	0 - unlikely	0

6.2.3 Determining those exposed

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

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

The sum of the factors (typically in the range between 3 to 9) provides an indication of the vulnerability of the area (as opposed to that of the people). This is shown in Table 6.2 for each of the hazard zones.

Table 6.2: Area vulnerability scores

Distance from river/coast (m)	Flood warning	Speed of onset	Nature of area	Sum = area vulnerability
0-50	2.15	3	2	7.15
50-100	2.15	2	1	5.15
100-250	2.15	2	3	7.15
250-500	2.15	1	2	5.15
500-1000	2.15	1	2	5.15

This area vulnerability score is simply multiplied by the hazard rating derived above to generate the value for X (the % of people exposed to risk) as shown in Table 6.3. Should the score exceed 100, this is simply taken as 100. Whilst this is not a true percentage, it provides a practical approach to the assessment of flood risk.

Table 6.3: 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	8.5	7.15	61%	15
50-100	50	5.6	5.15	29%	14
100-250	300	2.8	7.15	20%	60
250-500	1000	1.85	5.15	10%	95
500-1000	2500	0	5.15	0%	0

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

6.2.4 Determining numbers of deaths/injuries

The penultimate stage is to compute the numbers of deaths/injuries for this event before repeating the calculation for four more events. This step is achieved by multiplying the number of people exposed to the risk (N(ZE) from Table 6.3) by a factor Y which is based on the vulnerability of the people exposed.

As previously discussed Y is a function of two parameters: the presence of the very old; and those who are at risk due to disabilities or sickness. The resultant number of injuries is then simply the number of people at risk (from Table 6.3) multiplied by Y as shown in Table 6.5.

Table 6.4: Calculating People Vulnerability

Distance from river/coast (m)	N(Z)	Factor 1 (% very old)	Factor 2 (% Disabled or infirm)	Y
0-50	25	15%	10%	25%
50-100	50	10%	14%	24%
100-250	300	12%	10%	22%
250-500	1000	10%	15%	25%
500-1000	2500	15%	20%	35%

Table 6.5: Generating numbers of injuries and deaths

Distance from river /coast (m)	N(ZE) Table 6.3	Y = 1 + 2 (as %)	No. of injuries = 2 * Y * N(ZE)	Fatality rate = 2 x HR	No. of deaths
0-50	15	25%	8	17%	1
50-100	14	24%	7	11%	1
100-250	60	22%	26	6%	1
250-500	95	25%	48	4%	2
500-1000	0	35%	0	0%	0
All	185		89		5

It would be expected that in zones with a relatively high hazard rating (which is a function of depth, velocity and debris), there would be an increased probability of fatalities. It has been assumed that a factor of twice the hazard rating is appropriate, expressed as a percentage. Applying this factor (as shown in Table 6.5) provides an overall result of a predicted 44 injuries of which 3 are fatalities for the 1% probability flood event.

6.2.5 Step 2: Considering a range of events and estimating annual average risks

The same calculation must repeated for other flood events. A summary of injuries and deaths for all 5 events is shown in Table 6.6.

Table 6.6: The number of injuries and fatalities in Riskville for 5 flood events

Numbers injured					
Distance from river /coast (m)	1000yr	250yr	100yr	50yr	20yr
0-50	12	10	8	6	2
50-100	11	9	7	5	2
100-250	53	38	26	17	0
250-500	103	75	48	0	0
500-1000	243	158	0	0	0
All	421	289	89	28	4
Number of fatalities					
Distance from river /coast (m)	1000yr	250yr	100yr	50yr	20yr
0-50	3	2	1	1	0
50-100	2	1	1	0	0
100-250	6	3	1	1	0
250-500	8	4	2	0	0
500-1000	13	6	0	0	0
All	32	17	5	2	0

6.2.6 Step 3: Estimating acceptable risk

The concepts of 'tolerable' and 'acceptable' risks

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

Thresholds for 'tolerable' and 'acceptable' risk have been used in this example and other case studies in this report. These concepts, developed in Phase 1 of the research project (HR Wallingford, 2003), are valuable. However, current Government policy for flood risk management does not consider a specific threshold for tolerable risk so the values used in this report should be regarded as illustrative only.

The average annual individual risk can be calculated by combining the outputs from all 5 events as shown in Tables 6-7 for serious harm and 6-8 for fatalities.

The number of fatalities per year can be estimated in a similar way to annual average damage calculations as follows:-

Nf (/per year) = $\sum$ (df x Nf)

Where df is the frequency interval calculated as the difference in probability between adjacent events. Considering Table 6-8, the average annual risk of a fatality in Riskville is approximately 0.2 or 1 fatality on average every 5 years.

The acceptability of individual risk can be determined with reference to a specific policy objective, e.g. *"no development should increase the individual risk of flood fatalities*," or a threshold, for example an arbitrary threshold of 1 x 10^{-4} injuries per year is considered in Tables 6-7 and 6-8. Against this criteria flood risk in Riskville is unacceptable. Similarly societal risk can be considered in terms of the average number of injuries or fatalities for specific areas (e.g. in the UK, by region or catchments) or divided by unit area for mapping purposes.

Within the overall risks to people methodology, societal risk is particularly sensitive to the number of people located within the floodplain. Individual risk is more sensitive to area and people vulnerability factors so it can be mitigated by flood risk management activities including improved flood warning and development control that prevents low rise and other inappropriate development. It is inevitable that societal risk will increase if the population within the floodplain increases whereas individual risk.

This risks to people calculation was completed for four case studies including the recent floods in Carlisle in 2005 (Section 6.3). In addition the analysis was taken further to determine an acceptable population or number of houses of a specific type permitted without exceeding the acceptable risk threshold for three further examples that are included Appendix 2.

Table 6.7: Annual average individual risk for serious harm due to flooding in Riskville

Annual average individual risk							
Distance from river /coast (m)	1000yr	250yr	100yr	50yr	20yr	All events	Comments
Frequency per year (f)	**1.0E-03**	**4.0E-03**	**1.0E-02**	**2.0E-02**	**5.0E-02**		
Frequency interval (df)	**3.0E-03**	**6.0E-03**	**1.0E-02**	**3.0E-02**			
0-50	1.E-03	2.E-03	3.E-03	8.E-03	0.E+00	**1.5E-02**	Unacceptable risk
50-100	6.E-04	1.E-03	1.E-03	3.E-03	0.E+00	**6.1E-03**	"
100-250	5.E-04	8.E-04	9.E-04	2.E-03	0.E+00	**3.8E-03**	"
250-500	3.E-04	4.E-04	5.E-04	0.E+00	0.E+00	**1.2E-03**	"
500-1000	3.E-04	4.E-04	0.E+00	0.E+00	0.E+00	**6.7E-04**	Acceptable risk
All							
Tolerable risk threshold (harm)	1.0E-04 (Arbitrary value chosen for illustrative purposes)						

Table 6.8: Annual average individual risk of fatalities due to flooding is Riskville

Distance from river /coast (m)	1000yr	250yr	100yr	50yr	20yr	All events	
Frequency per year (f)	**1.0E-03**	**4.0E-03**	**1.0E-02**	**2.0E-02**	**5.0E-02**		
Frequency interval (df)	**3.0E-03**	**6.0E-03**	**1.0E-02**	**3.0E-02**			
0-50	4.E-04	6.E-04	5.E-04	1.E-03	0.E+00	**2.6E-03**	Unacceptable risk
50-100	1.E-04	2.E-04	2.E-04	2.E-04	0.E+00	**6.6E-04**	“
100-250	6.E-05	6.E-05	5.E-05	6.E-05	0.E+00	**2.3E-04**	“
250-500	2.E-05	3.E-05	2.E-05	0.E+00	0.E+00	**6.8E-05**	Acceptable
500-1000	2.E-05	1.E-05	0.E+00	0.E+00	0.E+00	**2.9E-05**	“
Tolerable risk threshold (fatality)	1.0E-05	(Arbitrary value chosen for illustrative purposes)					

6.3 Case studies

6.3.1 Introduction

In the Phase 1 Report, the ‘old’ methodology was applied to three past flood events to examine whether the results were consistent with historical observations. The three flood events considered were:

- Gowdall, 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;
- Norwich which suffered extreme flooding in 1912 with, perhaps, 2,500 people flooded; and
- Lynmouth which suffered a devastating flood in August 1952 due to very rapid flow down the East and West Lyn rivers.

These three case studies have been re-assessed together with the recent flooding in Carlisle using the revised methodology as outlined below.

6.3.2 Gowdall

Areas at Risk
Over one hundred properties were reported to have been flooded in Gowdall in the autumn 2000 floods. Gowdall is located within the Snaith, Airmyn and Rawclife and

Marshland Ward (of the East Riding of Yorkshire) which has an average of 2.4 people per household[3]. This gives the number of people to be at risk as around 250.

Flood Depth
For simplicity, the whole of the flooded area will be taken as a single hazard zone with a flood depth, d, of 1.0m.

Flood Velocity
The build up of floodwaters was very gradual and, for the purposes of this analysis, a general value for velocity, v, of 0.5 m/sec will be assumed.

Debris Factor
There were no reports of significant amounts of debris. On this basis, the debris factor (DF) has been taken as zero.

Hazard Rating
The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above gives: $HR = 1 \times (0.5 + 0.5) + 0 = 1$

Flood Warning
The score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). Based on the results of 36 interviews amongst those that had been flooded in Gowdall (which were undertaken as part of the 'intangibles' study (RPA, 2004)), nearly 80% of respondents had received flood warnings many hours before the flooding occurred. On this basis a score of 1 has been assigned to this factor.

Speed of Onset
As already indicated, the speed of onset of flooding in Gowdall was 'very gradual' which attracts a score of 1.

Nature of Area
Gowdall is a typical 'medium' risk residential area which attracts a score of 2.

Area Vulnerability Score
The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 4 (which indicates a low risk area).

Long Term Illness & The Very Old
Based on statistics for the ward containing Gowdall, 18.1% of the population have a limiting long-term illness (and/or disability) and 7.0% of the population are 75 or over.

People Vulnerability Score
The people vulnerability (PV) score is simply the sum of the above factors to give PV = 25.1%. For comparison, the national figures are 18.2% and 7.6% respectively to give a combined score of 25.8%. As such, those at risk are no more vulnerable than the general population.

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[3] This and subsequent statistics for Gowdall are based on data from the 2001 Census as obtained from http://neighbourhood.statistics.gov.uk (by entering a local postcode).

Numbers of Injuries and Fatalities
Estimates of the numbers of injuries (Ninj) and fatalities (Nf) can be made using the formulae:

$$Ninj = 2 \times Nz \times HR \times AV/100 \times PV$$

$$Nf = 2 \times Ninj \times HR/100$$

As described above, the values derived for Gowdall are:

Nz = number of people at risk = 250
HR = hazard rating = 1
AV = area vulnerability = 4
PV = people vulnerability = 25.1%

Substituting these values gives: Ninj = 5 and Nf = 0.1.

These results are consistent with the findings from the 'intangibles' study (RPA, 2004) 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.

6.3.3 Norwich

Areas at Risk
Norwich suffered extreme flooding in 1912 with, perhaps, 2,500 people flooded. 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).

Flood Depth
Flood depths, d, have been taken as 1.5m in the zone closest to the river and 1m for the zone further away.

Flood Velocity
Flood velocities, v, have been taken as 1.0 and 0.2 m/sec for the two zones respectively.

Debris Factor
There were no reports of significant amounts of debris. On this basis, the debris factor (DF) has been taken as zero.

Hazard rating
The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above is shown in Table 6.9

Table 6.9: Hazard Rating by Zone for Norwich 1912

Distance from river	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating= d(v + 0.5) + DF
<50m	1.5	1	0	2.25
>50m	1	0.2	0	0.7

Flood Warning
The score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). In 1912, there was effectively no flood warning and a score of 3 has been assigned to this factor.

Speed of Onset
Based on reports from the time, the speed of onset of flooding in Norwich was 'very gradual' which attracts a score of 1.

Nature of Area
The flooded area was a typical 'medium' risk residential area which attracts a score of 2.

Area Vulnerability Score
The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 6 (which indicates a medium risk area).

Long Term Illness & The Very Old
Detailed statistics for these factors for the flooded areas are not readily available. However, the proportion of the population over 75 in 1912 would be several times lower than today's national average of 7.6%[4]. In terms of those with long-term illness and/or disabilities, it would be expected that the proportion would be greater than today's national figure of 18.2% - particularly as the areas flooded in Norwich comprised many poor areas of housing (i.e. slums)

People Vulnerability Score
The people vulnerability (PV) score has been taken as today's national average of 25.8% (based on a lower percentage over 75 but a higher percentage for long term illness and/or disability).

Numbers of Injuries and Fatalities
Estimates of the numbers of injuries (Ninj) and fatalities (Nf) can be made using the formulae:

$$Ninj = 2 \times Nz \times HR \times AV/100 \times PV$$

$$Nf = 2 \times Ninj \times HR/100$$

The values derived for Norwich are shown in Table 6.10

Table 6.10: Numbers of Injuries and Fatalities for Norwich 1912

Zone	Nz	HR	AV	PV	Ninj	Nf
<50m	500	2.25	6	25.8%	35	1.6
>50m	2000	0.7	6	25.8%	43	0.6
All	2500				78	2.2

These results appear reasonable and are consistent with the four deaths reported.

4 The 1911 Census indicates that the proportion of Norwich's population aged over 65 has doubled from around 6.5% in 1911 to ?? in 2001.

6.3.4 Lynmouth

Areas at Risk
Lynmouth suffered a devastating flood in August 1952 due to very rapid flow down the East and West Lyn rivers. Various articles have been reviewed and for the purposes of this analysis, three hazard zones (A, B and C) are taken where these have been based on the numbers of houses destroyed (38), houses severely damaged (55) and houses damaged (72).

Flood Depth
Flood depths, d, have been taken as 3, 2 and 1m in Zones A, B and C respectively.

Flood Velocity
Flood velocities, v, have been taken as 4, 3 and 2 m/sec in Zones A, B and C respectively.

Debris Factor
Debris was significant and a value of 1 has been assumed for Zones A and B and 0.5 in Zone C.

Hazard rating
The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above is shown in Table 6.11

Table 6.11: Hazard Rating by Zone for Lynmouth 1952

Zone	Distance from river	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating= d(v + 0.5) + DF
A	Very close	3	4	1	14.5
B	Close	2	3	1	8
C	Nearby	1	2	0.5	3

Flood Warning
The score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). There was effectively no flood warning and a score of 3 has been assigned to this factor.

Speed of Onset
The speed of onset of flooding in Lynmouth was rapid which attracts a score of 3.

Nature of Area
The flooded area was a typical 'medium' risk residential area which attracts a score of 2.

Area Vulnerability Score
The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 8 (which indicates a high risk area).

Long Term Illness & The Very Old
Detailed statistics for these factors for the flooded areas are not readily available. For the purposes of this analysis, the people vulnerability (PV) score has been taken as today's national average of 25.8%.

Numbers of Injuries and Fatalities
Estimates of the numbers of injuries (Ninj) and fatalities (Nf) can be made using the formulae:

$$Ninj = 2 \times Nz \times HR \times AV/100 \times PV$$

$$Nf = 2 \times Ninj \times HR/100$$

The values derived for Lynmouth are shown in Table 6.12

Table 6.12: Numbers of Injuries and Fatalities for Lynmouth 1952

Zone	Nz	HR	AV	PV	Ninj	Nf
A	100	14.5			60	17
B	100	8	8	25.8%	33	5
C	200	3			25	3
All	400				118	24

These results presented above are consistent with the total of 34 deaths reported.

6.3.5 Carlisle

Areas at Risk

Carlisle suffered severe flooding on 8th January 2005 following a period of heavy rainfall. Various notes by the Environment Agency and others have been reviewed together with a very useful photographic record (Ramshaw, 2005). For the purposes of this analysis, five hazard zones have been taken:

- Zone A: The Willow Holme industrial area contains some 160 commercial/industrial premises. This area is bounded by the River Eden to the north and the River Caldew to the east and was flooded to a depth of around 1.5m;
- Zone B: This area immediately to the south of Bridge Street is on the west bank of the River Caldew and contains around 200 residential properties which were flooded to a typical depth of around 1.0m;
- Zone C: The City Centre area was flooded to a depth of around 1.5m with around 33 residential properties (centred on Corporation Road) and 18 non-residential premises affected;
- Zone D: Further east, the Warwick Road area (particularly around the Botcherby Bridge) was flooded to a depth of 1.5m. For this analysis, 400 residential properties and 12 non-residential premises are assumed to have been flooded; and
- Zone E: The residential areas around the Warwick Road area were also flooded but to a lesser depth. For this analysis, flooding of a further 700 residential properties and 15 non-residential premises are assumed to have been flooded to a depth of 0.5m.

Flood Depth

As indicated above, flood depths have been taken as 1.5m in Zones A, C and D; 1.0m in Zone B; and 0.5m in Zone E.

Flood Velocity

Based on an inspection of photographs taken during the course of the flooding, it would appear that the flood velocity, v, was not great and a value of 0.5 m/sec has been assumed for all zones.

Debris Factor

Very little debris was observed during the flood and, consequently, a value of 0 has been assumed for all zones.

Hazard rating

The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above is shown in Table 6.13

Table 6.13: Hazard Rating by Zone for Carlisle 2005

Zone	Location	Typical depth, d (m)	Typical velocity, v (m/sec)	Debris factor (DF)	Hazard rating= d(v + 0.5) + DF
A	Willow Holme	1.5	0.5	0	1.5
B	S. of Bridge St	1.0			1.0
C	City Centre	1.5			1.5
D	Warwick Rd. 1	1.5			1.5
E	Warwick Rd. 2	0.5			0.5

Flood Warning
The score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). Based on accounts provided by the Environment Agency, it would appear that there were good flood warnings for Zones A and C attracting a score of 1 but not so good for the other zones attracting a score of 2. It should be noted that all zones were provided with a general floodwatch alert prior to the flooding.

Speed of Onset
The speed of onset of flooding in Carlisle was very gradual (attracting a score of 1) with initial flooding occurring in the early hours of the morning followed by a gradual inundation which peaked around lunchtime.

Nature of Area
The flooded area was a typical 'medium' risk residential/commercial area which attracts a score of 2.

Area Vulnerability Score
The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 4 in Zones A and C (which indicates a low risk area) and AV = 5 in Zones B, D and E (which indicate a medium risk area).

People Vulnerability Score
Detailed statistics for those with a long term illness and/or disability and the very old for the flooded areas were taken from the ward statistics (based on the 2001 Census) in order to generate the People Vulnerability (PV) scores as summarised in Table 6.14

Table 6.14: People Vulnerability by Zone for Carlisle 2005

Zone	Location	Ward	%Long Term Illness/Disability	%>75	PV Score
A	Willow Holme	n/a	5.0%	2.0%	7.0%
B	S. of Bridge St	Denton Holme	20.0%	8.3%	28.3%
C	City Centre	Castle	22.0%	6.5%	28.5%
D	Warwick Rd. 1	St Aidans/ Botcherby	19.7%	7.2%	26.9%
E	Warwick Rd. 2				

Zone A is an industrial area and the proportions of those with long term illness/disability and those over 75 would be expected to be significantly lower than for the other zones.

Numbers of Injuries and Fatalities

Estimates of the numbers of injuries (Ninj) and fatalities (Nf) can be made using the formulae:

$$\text{Ninj} = 2 \times \text{Nz} \times \text{HR} \times \text{AV}/100 \times \text{PV}$$

$$\text{Nf} = 2 \times \text{Ninj} \times \text{HR}/100$$

The values for Nz (the number of people at risk) were derived= by zone as shown in Table 6.15 using an assumed value of four persons per non-residential premises.

Table 6.15: Numbers at Risk (Nz) by Zone for Carlisle 2005

Zone	Ward	No. res. props	People/property	No. non-res properties	Nz
A	n/a	0	n/a	160	640
B	Denton Holme	200	2.1	0	420
C	Castle	33	1.9	18	135
D	St Aidans/ Botcherby	400	2.1	12	888
E		700		15	1530

Zone A is an industrial area and the proportions of those with long term illness/disability and those over 75 would be expected to be significantly lower than for the other zones.

The predicted numbers of injuries and fatalities for Carlisle are shown in Table 6.16

Table 6.16: Numbers of Injuries and Fatalities for Carlisle 2005

Zone	Nz	HR	AV	PV	Ninj	Nf
A	640	1.5	4	7.0%	5	0.2
B	420	1.0	5	28.3%	12	0.2
C	135	1.5	4	28.5%	5	0.1
D	888	1.5	5	26.9%	36	1.1
E	1530	0.5			21	0.2
All	**3613**				**78**	**2**

These results are consistent with reports[5] of “three dead and 100 people were treated for injuries in the Carlisle area”- although one death was outside Carlisle. It is understood that the two deaths in Carlisle involved elderly women in the deeply flooded Warwick Road area (i.e. in Zone D).

[5] See, for example, the report of 10 January 2005 from Willis (a major insurer) entitled: *Catastrophe Report - North West Europe Weather Alert January 8-10, 2005* (from www.willisre.com)

6.3.6 Further case studies

Other case studies were developed as part of a separate project – Appendix 2 includes "Annex Q" of a the project report for research on acceptable risk completed by RPA for the Environment Agency. This annex provides a link between the two projects.

7. MAPPING FLOOD RISKS TO PEOPLE

This section describes a general approach for mapping flood risks to people. Sources of information and mapping approaches are described for flood hazard, flood vulnerability and Risks to People mapping.

- A **Flood Hazard map** provides information on the flood conditions that harm people during a flood. The Risk to People Flood Hazard maps are based on flood depths, velocities and the presence of debris (Section **) with the results classified into Low, Medium and High Hazard classes. A Flood Hazard map can present the hazards associated with a single event (e.g. a 1% fluvial flood in an undefended floodplain) or a combination of events (e.g. coastal flood events that occur due to the combined probability of high water levels and failure of flood defences).
- A **Flood Vulnerability map** provides information on vulnerability of people to flooding. The Risk to People Flood Vulnerability maps are based on the concepts of Area and People Vulnerability and the scoring system described in Sections 4 and 5. A flood vulnerability map classifies all areas within an extreme flood outline according to area and population characteristics. Vulnerability can be classified into Low, Medium and High classes.
- A **Risks to People** map combines Flood Hazard and Vulnerability maps using the Risks to People methodology. It describes the individual or societal risk of serious harm as an annual average risk based on the consideration of at least 5 event probabilities. The maps can be classified into classes with references to the concept of Acceptable Risk.

Mapping issues related to the level of detail of flood risk assessment, accuracy of different sources of data, scale and presentation of outputs are discussed. However the general approach will need to be adapted to fit specific applications of the Risks to People methodology.

7.1 Flood Hazard mapping

Flood hazard mapping requires data on flood depth, flood velocity and a debris factor.

The main sources of data for flood hazard mapping are summarised in Table 7-1.

Table 7.1: Variables required and sources of data for Flood Hazard mapping

Variable	Type	Sources
Depth (m)	Variable	• Flood extents and topographic data (Digital Elevation Models based on Ordnance Survey, NEXTMAP, filtered LiDAR or local topographic survey) • 1-D hydraulic models (e.g. ISIS, MIKE11) • 2-D hydraulic models (e.g. TuFLOW) • Floodplain Information Systems
Velocity (ms^{-1})	Variable	• Expert judgement (for broad-brush or "high-level" risk assessment only ~ see guidance below) • 1-D hydraulic models (e.g. ISIS, MIKE11)

		• 2-D hydraulic models (e.g. TuFLOW).
Debris	Score	• Expert judgement (See guidance below)
Base mapping	N/A	• Ordnance Survey (OS) MasterMap • OS Raster mapping

There are a range of hydraulic modelling methods that can be used to provide flood **depths** and **velocities**.

Flood velocities produced by one and two-dimensional models will be average velocities for a cross-section or grid cell. There will be considerable variation of flow velocities within a river cross-section and for all modelling approaches peak flow velocities may be much higher than the average velocities reported for a cross-section or grid-cell. This is particularly the case in urban areas where flows may be concentrated in narrow streets and between buildings.

Methods for estimating flood depths and velocities are summarised below (in the order of least complex to most complex):-

- Existing flood maps and topographic data. Existing maps can be used to estimate flood depth but do not provide any information on velocities. For some simple applications of the method it may be appropriate to estimate peak velocities based on normal depth calculations or even expert judgement. Any assumptions made should be conservative (assuming high velocities). Further more detailed assessments should be completed if the Risks to People mapping highlights areas where the risks are unacceptable.
- Conveyance calculation. The new Conveyance Estimation System (CES) can be used to estimate velocities across a floodplain for river valleys without defences (see http://www.river-conveyance.net).
- One-dimensional hydraulic models with defined flood storage areas and active floodplain channels e.g. ISIS Flow or MIKE11 software, can be used to estimate average velocities. Maximum velocities will be significantly higher in some parts of the floodplain, e.g. where water spills over a defence, in narrow streets and any other "pinch points" in the floodplain.
- Flow routing using a "raster" GIS system e.g. the LISFLOOD-FP model used for the fluvial component of the Extreme Flood Outline project (see below).
- Two-dimensional hydraulic modelling using a fixed grid, e.g. the TUFLOW hydraulic model that has been used for modelling the tidal Thames (Tarrant *et al.,* 2005) or HYDRO F (Atkins) that was used for the tidal component of the Extreme Flood Outline project (see below).
- Two-dimensional hydraulic modelling using a triangular mesh, e.g. the Telemac 2D model. This can provide good velocity estimates but model run times are significantly longer than grid based models.

7.1.1 The Environment Agency Flood Maps

The Environment Agency's current Flood Maps show the 1% fluvial, 0.5% tidal and 0.1% flood extents and additional information on the presence of flood defences.

Different versions of national flood maps have been based on a combination of the following:-

- One-dimensional river modelling completed as part of the Section 105 floodplain mapping programme. The 1% fluvial flood and 0.5% tidal flood events are shown on the Environment Agency's web page. The S105 specification included modelling a range of return periods and the requirement to include precautionary allowances and sensitivity tests for climate change. In some Environment Agency regions information on flood probability, depth and velocities were stored in a GIS based Floodplain Information System (FPI).
- Two-dimensional modelling of an Extreme Flood Outline (0.1% probability) assuming no defences completed with JFLOW (Fluvial) and HYDRO F (Tidal) and historical flood outlines.
- In areas where modelling has not been completed flood maps are based on either the Centre for Ecology and Hydrology (formerly Institute of Hydrology) Report No. 130, Flood risk map of England and Wales or historical flood outlines of the worst flood on record.
- Information on the presence of flood defences and defended areas from the National Flood and Coastal Defences Database.

The national Environment Agency maps are updated annually/quarterly (?) and are subject to an ongoing programme of development as part of the national Flood Risk Mapping programme.

In the context of Risks to People the national maps and underlying hydraulic models provide a readily available source of information that could be used for specific applications. For example, for Catchment Floodplain Management Plans (CFMPs) or for prioritising flood warning on a catchment by catchment basis. For emergency planning more detailed 2-D modelling is required; flood hazard mapping needs to be local and detailed, highlighting areas of high flood hazard and details such as "safe" access and exit routes for the emergency services.

7.1.2 Catchment Flood Management Plans

Simplified hydraulic modelling and flood mapping also forms part of Catchment Flood Management Plans (CFMPs) that are being implemented as part of a national programme. The CFMP guidance provides a framework but is not prescriptive regarding approaches to modelling and mapping. There is a requirement to consider 5 scenarios including flood events of different return periods and to take account of climate change. Therefore, flood hazard zones could be defined based on 5 different flood extents and reach lengths (dependent of spacing of simplified model nodes). Depths would be easy to estimate but a simple method is required to estimate velocity.

Further guidance on risks to people for CFMPs is provided in FD2321/TR2.

7.1.3 Risk Assessment for Strategic Planning

At a regional and national scale, a number of research projects have used the Risk Assessment and Strategic Planning (RASP) tool to estimate the number of properties and people affected by flooding. The RASP tool includes methods for estimating the combined probability of extreme water levels and defence failures, flood extent and depths (HR Wallingford, 2004). In the context of mapping Risks to People, the RASP approach is particularly relevant for mapping:-

(a) individual and societal risk at the national and regional scales. The inclusion of risks to people will provide additional risk metrics to consider alongside economic assessments of flood damage.

(b) flood hazard and risks to people in areas with complex flood defence systems where flood events are due to the combined probability of "forcing variables" and defence failure and the failure of different individual defences will affect different areas of the floodplain.

7.1.4 Four steps for Flood Hazard mapping

As part of the general approach for Flood Hazard mapping as an input to the Risks to People methodology, there are four important steps that should be taken:-

1. Define the problem
   - Establish clear aims & objectives
   - Define the spatial extent of the study
   - Define the level of risk assessment
   - Consider components of the flood defence system
2. Develop an understanding of flood hazard.
   - Review existing flood zones maps or more detailed local modelling studies
   - Review output from existing hydraulic models, use the best available floodplain topography, identify flow paths, identify the need and scope of any new survey and hydraulic models.
3. Define "flood hazard zones" based on one of the following (and depending on the scale and level of risk assessment):-
   - Distance from the source of flooding and reach length
   - Topographic contours and reach lengths
   - Existing flood outlines for ca. 5 return periods
   - Flood hazard classes from an extreme flood (e.g. the 0.1% flood outline)
   - Flood defence system components
   - *Note that flood hazard zones should be overlaid with the "nature of area" zones to define "risks to people" zones that are used in the calculations.*
4. Produce flood hazard maps combining model information on max flood depth, velocity and debris for "n" return periods.
   - Estimate flood hazard for each return period on a grid cell basis.
   - Generalise flood hazard values for each flood hazard zone
   - Collate flood hazard values for each RP event (if an "annual average" type product fits with aims and objectives).
   - Flood hazard should only be presented as a flood hazard class.

- For areas with complex flood defence systems and for some applications a map of maximum flood hazard considering breaches and overtopping in a range of events would be more informative than a map of single extreme event.

7.1.5 Flood Hazard mapping for different applications

The calculation of flood hazard scores by zones is required for the Risks to People methodology. The approach to mapping will be different for specific applications, different levels or risk assessment and spatial scales.

An example of how different approached could be taken for each step of the flood hazard mapping process is shown in Figure 7-1.

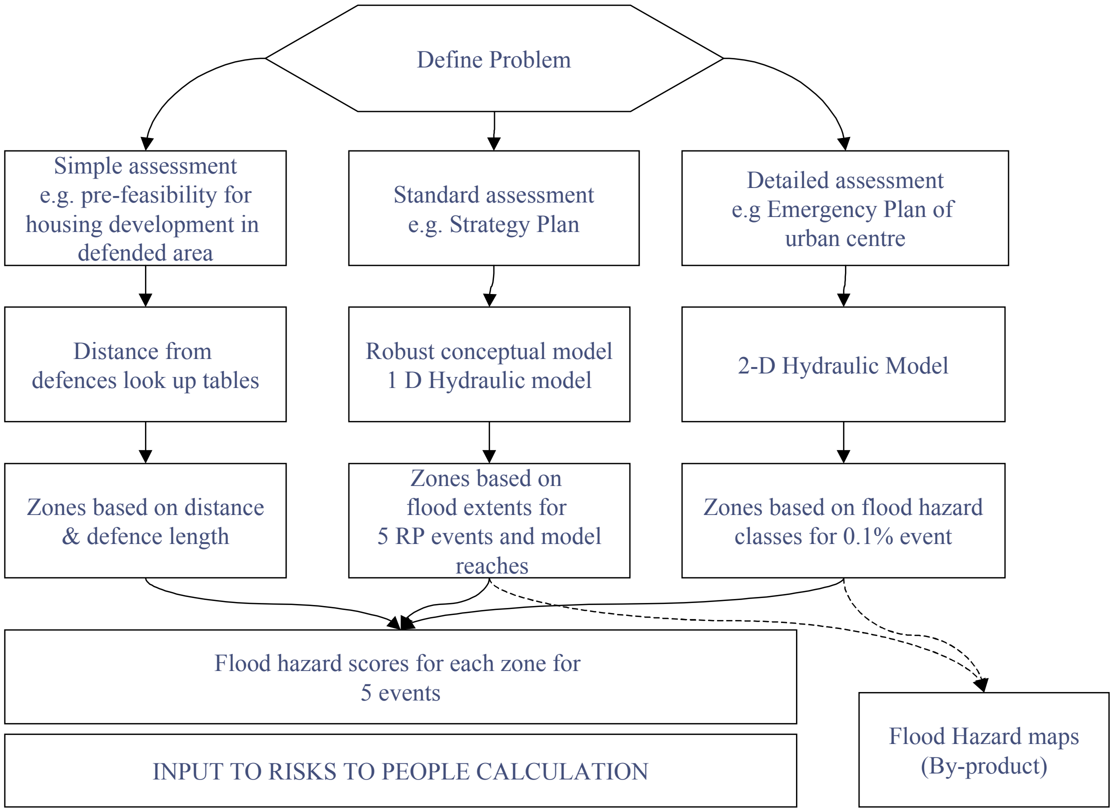


Figure 7.1: Examples of potential approaches to flood hazard mapping

Examples of flood hazard maps based on 2-D modelling are shown in at the end of this section.

7.2 Flood vulnerability mapping

Flood vulnerability maps are an interim stage of the risks to people method. Mapping of the "nature of area" variable is particularly important for the risks to people calculation but flood vulnerability maps are not a required output *per se*. Flood vulnerability maps may be a useful by-product for other flood risk management activities.

Flood vulnerability is related to characteristics of the floodplain area and people at risk. Sections 4 and 5 sets out the factors considered as part of the Risks to People method and Table 7-3 summarises the sources of data for flood vulnerability mapping.

Table 7.2: Variables required and sources of data for Flood Vulnerability mapping

Area Vulnerability		
Variable	**Type**	**Sources**
Flood warning	Score	• Based on Environment Agency performance indicators (See Section 4).
Speed of onset	Score	• Based on catchment characteristics and nature of defences
Nature of area	Score	• Ordnance Survey (OS) mapping (Master Map & OS Address-point) • Proprietary address-point products • Local knowledge • The following should be highlighted on the maps and influence the delineation of *"nature of area"* zones: -areas of bungalows, mobile homes, busy roads, parks, single storey schools, campsites and other areas that do not provide safe refuge above the maximum flood water level. The use of OS Master Map and other proprietary databases e.g. FOCUS and GIS processing will enable these entities to be identified without the need for additional digitising.
People Vulnerability		
Variable	**Type**	**Sources**
%residents suffering from long-term illness	%	• National Census (Output Areas)
%residents aged 75 or over.	%	• National Census (Output Areas)
Population		

Population estimates (residents, workers and visitors)	No. per zone or km^2	• National Census (Output Areas)
		• The census and other data, such as Address-point can be used to develop population grids or counts for individual "impact zones":-
		  • OS Address-point. Property counts x occupancy rates (residential)
		  • Proprietary address-point data. Property counts x no. of employees x occupancy rate (0.33 for an 8 hour day) (non-residential)
		  • Transport network. Major transport routes (motorway, trunk road and rail) should be mapped as part of Area Vulnerability. Traffic density data can be used to estimate average population in transit per km (Highways Agency and Strategic Rail

		Authority statistics) • In addition it may be appropriate to make further population estimates for specific areas within the floodplain, e.g. public open places, parks, coastal promenades and beaches. (Estimate based on visitor numbers); camp-sites, hospitals and prisons.

7.2.1 Four steps for flood vulnerability mapping

Similar to flood hazard mapping there are several steps required to develop flood vulnerability maps:-

1. Define the problem
   - Establish clear aims & objectives
   - Define the spatial extent of the study
   - Define the level of risk assessment
2. Develop an understanding of flood vulnerability
   - Review Ordnance Survey maps
   - Review census data
   - For detailed projects, consult Area EA and local authority staff with local knowledge
3. Define "nature of area" zones
   - For national, regional or simple risks assessment it may be appropriate to use existing boundaries such as Enumeration Districts.
   - For more local or detailed applications areas should be delineated using the available information. This may be a manual task or it could be automated using "intelligent" mapping products (e.g. where building outlines and boundaries include attributes describing land use).
   - *Note that "nature of area" zones should be overlaid with flood hazard zones to define "risks to people" zones that are used in the calculations.*
4. Collate or interpolate population and census data into the "risks to people" zones.
   - Score flood warning and speed of onset.
   - Collate or interpolate census attributes into risks to people zones.
   - Use Address-point and other proprietary point data sets to estimate populations using consistent assumptions.

7.2.2 Access to census data

Data for the 2001 Census for Output Areas can be downloaded from the following link: http://neighbourhood.statistics.gov.uk/ (Then "find detailed data by subject" and select the 2001 census).

It should be noted, however, that the ONS website makes this data available on a regional, rather than a national basis. To obtain national coverage would therefore involve downloading ten data sets. If national coverage is desired, it would be more convenient to order the data from: http://www.statistics.gov.uk/census2001/pdfs/order_form.pdf

The Output Area GIS maps (Shape or Mid/Mif formats) can also be ordered on the same form. According to the ONS, there is no charge for the above information.

7.3 Risks to People maps

Once the risks to people zones are clearly defined it is a relatively simple process to complete the risks to people calculation for each zone, either within a GIS or in a spreadsheet.

Careful consideration is required in how risks to people maps are presented and used in the public domain. The use of qualitative risk classes may be more appropriate than quantitative presentation of individual or societal risk.

7.3.1 The development of specialist mapping products

There are a range of potential applications for flood hazard, flood vulnerability and risks to people maps. For example:-

- In strategic planning the full risk to people method could be used with the concept of acceptable risk to allocate a maximum number of people or house to each risks to people zone. (See examples in Annex Q).
- For emergency response, flood hazard maps could be classified to ensure that emergency personnel are aware of moderate and significant hazards for themselves and their vehicles. Emergency response routes and “safe” zones could be designated based on an extreme flood scenario.
- For flood warning, risks to people could be considered with flood warning areas or on a catchment by catchment basis to target warning and possibly funding in improved warning systems where these will reduce the risks to people.

It is not possible to describe “how to” develop specialists maps, however some further guidance on mapping and how the approach could be applied in different areas of flood risk management is provided in the accompanying guidance document.

7.3.2 Broad-scale mapping

For national and regional mapping the Risks to People methodology could be integrated into the Risk Assessment for Strategic Planning (RASP) framework. This would have a number of benefits:-

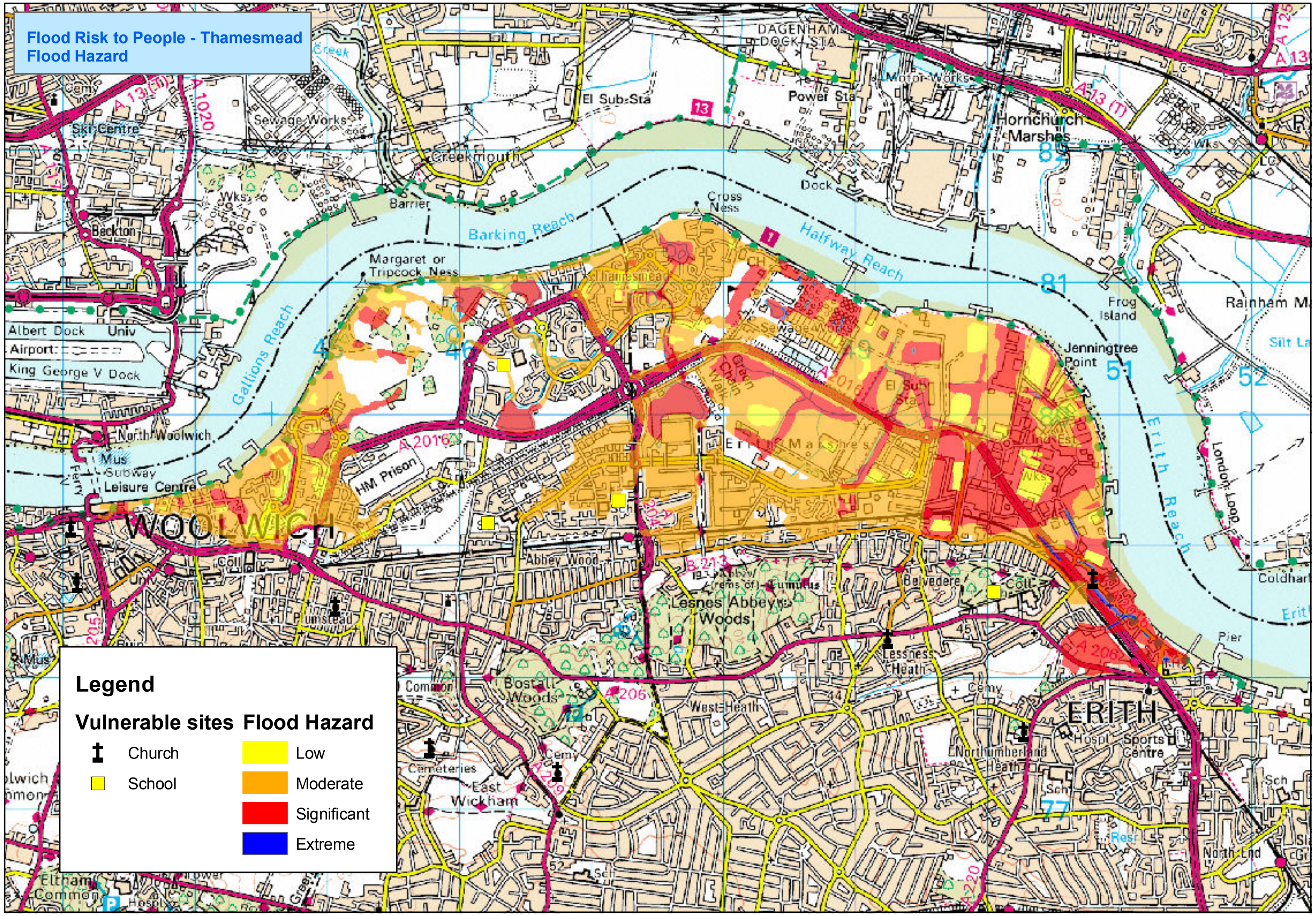
- RASP already provides an approach for considering the combined probability of “forcing” variables (water level, waves) and defence failure.
- Average annual individual or societal risk will provide another metric that can be considered alongside economic costs and benefits.

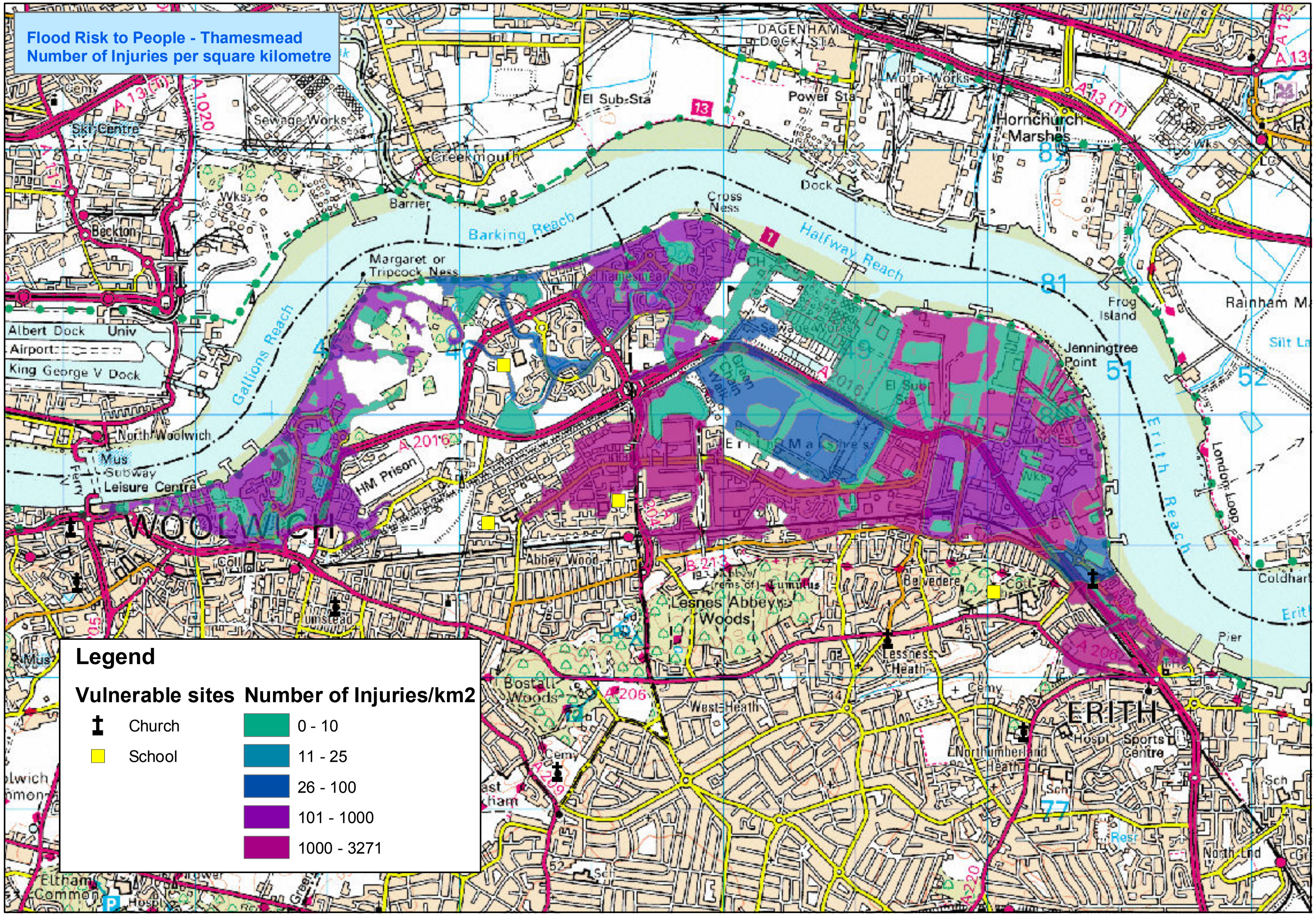
7.4 Mapping examples

7.4.1 Thamesmead

Map 1 – An example of broad flood hazard zones. These were based of reviewing modelling output for the 0.1% flood event with addition of water level to account for climate change to 2050. The zones can be digitised or derived using GIS processing of hydraulic model grids.
Map 2 – A flood hazard map for the same event.
Map 3 – The number of injuries per unit area. If the results from several larger events were combined then the map could show annual average societal risk.

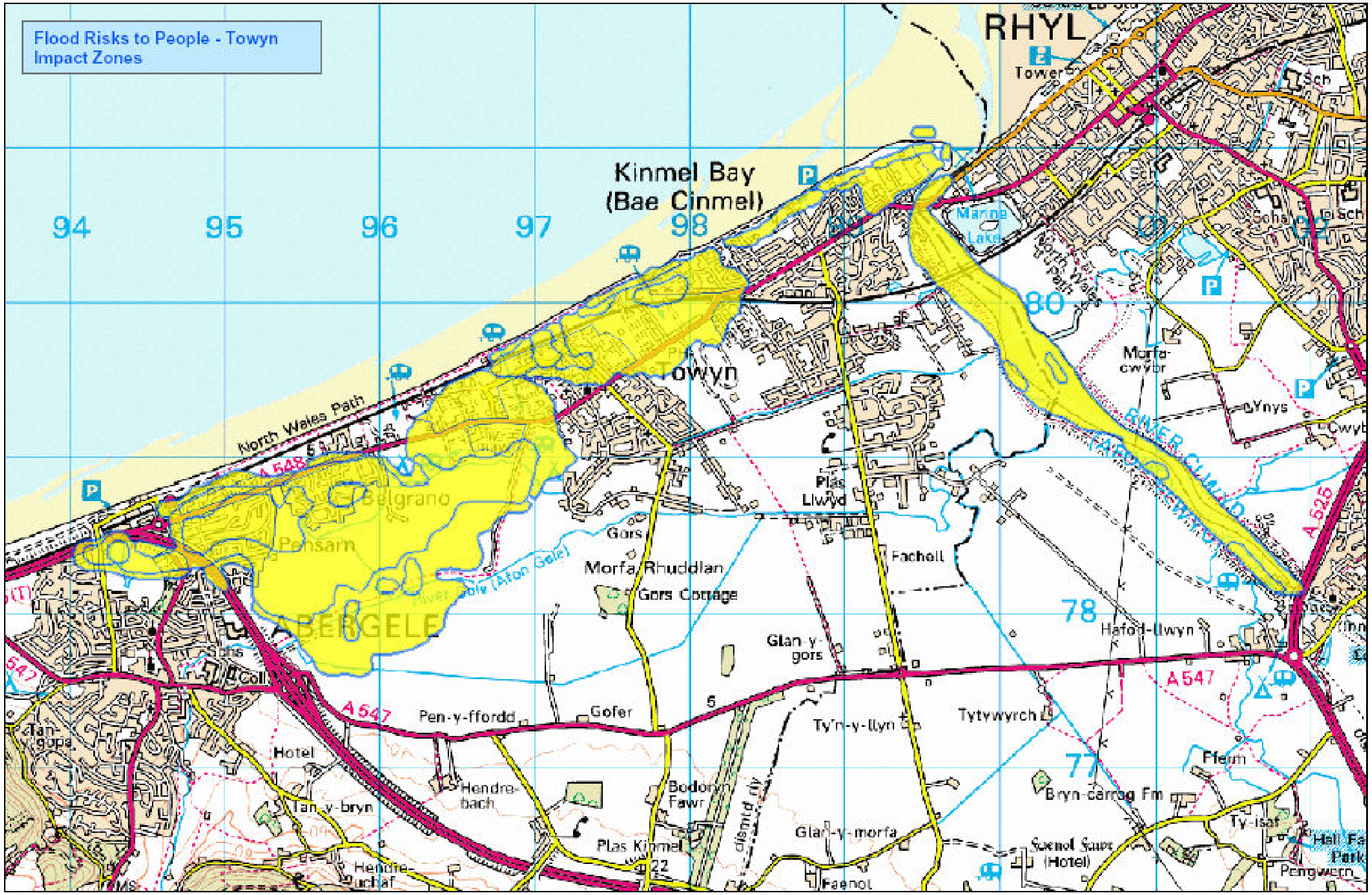

Flood Risk to People - Thamesmead
Impact zones
Barking Reach
Halfway Reach
Gallions Reach
Erith Reach
Margaret or Tripcock Ness
Cross Ness
Jenningtree Point
Frog Island
HM Prison
ERITH
Creekmouth
Albert Dock
King George V Dock
North Woolwich
Leisure Centre
Lesnes Abbey Woods
Bostall Woods
Abbey Wood
Plumstead Common
East Wickham
Shooters Hill
Belvedere
Hornchurch Marshes
Rainham Marshes
Sewage Works
Beckton
Dagenham Dock Sta
Power Sta
Sports Centre
Northumberland Heath
West Heath
London Loop
Green Chain Walk

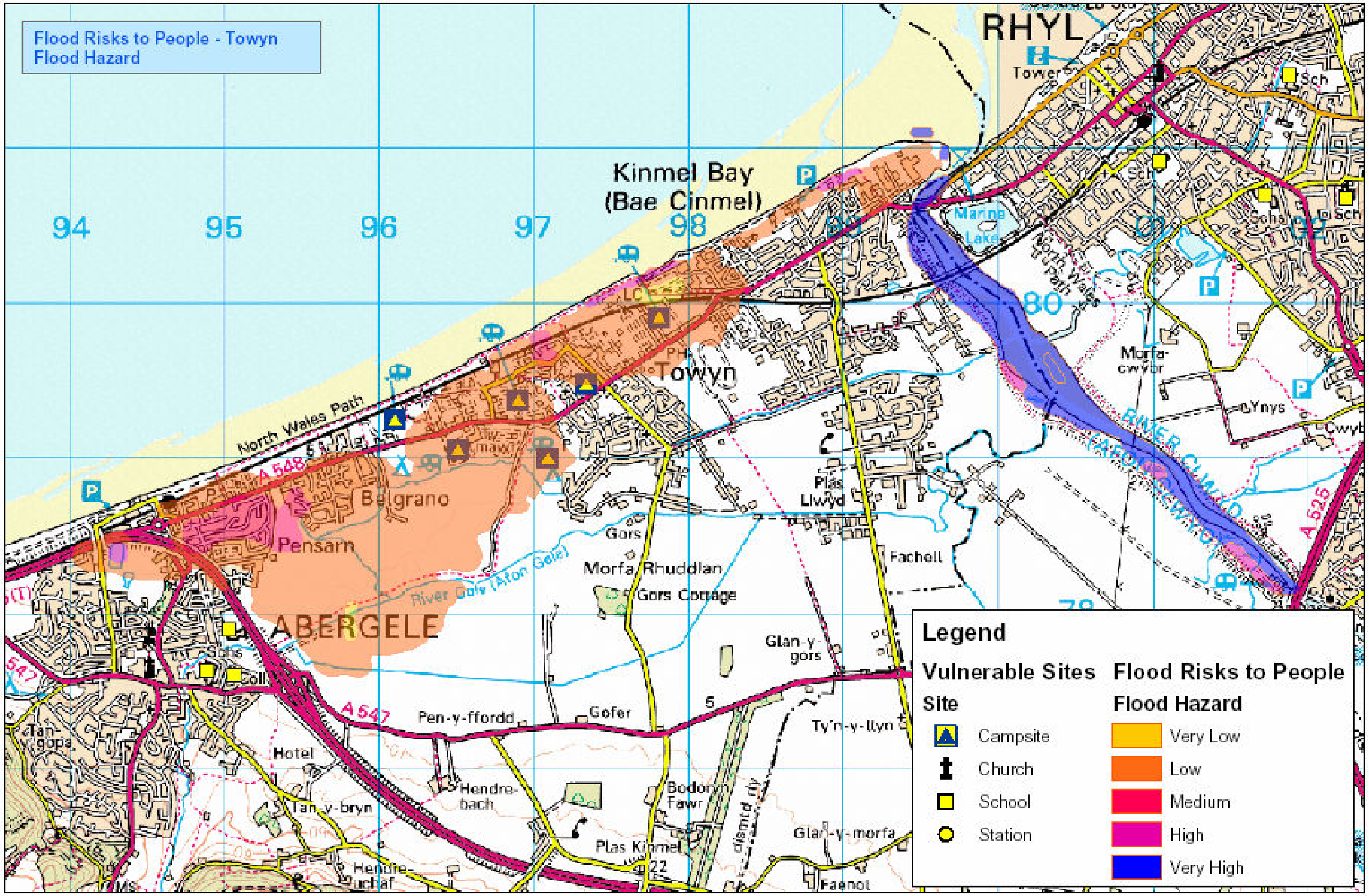

Flood Risk to People - Thamesmead
Flood Hazard
Legend
Vulnerable sites
Church
School
Flood Hazard
Low
Moderate
Significant
Extreme
WOOLWICH
ERITH
Barking Reach
Gallions Reach
Halfway Reach
Erith Reach
HM Prison
Lesnes Abbey Woods
Thamesmead

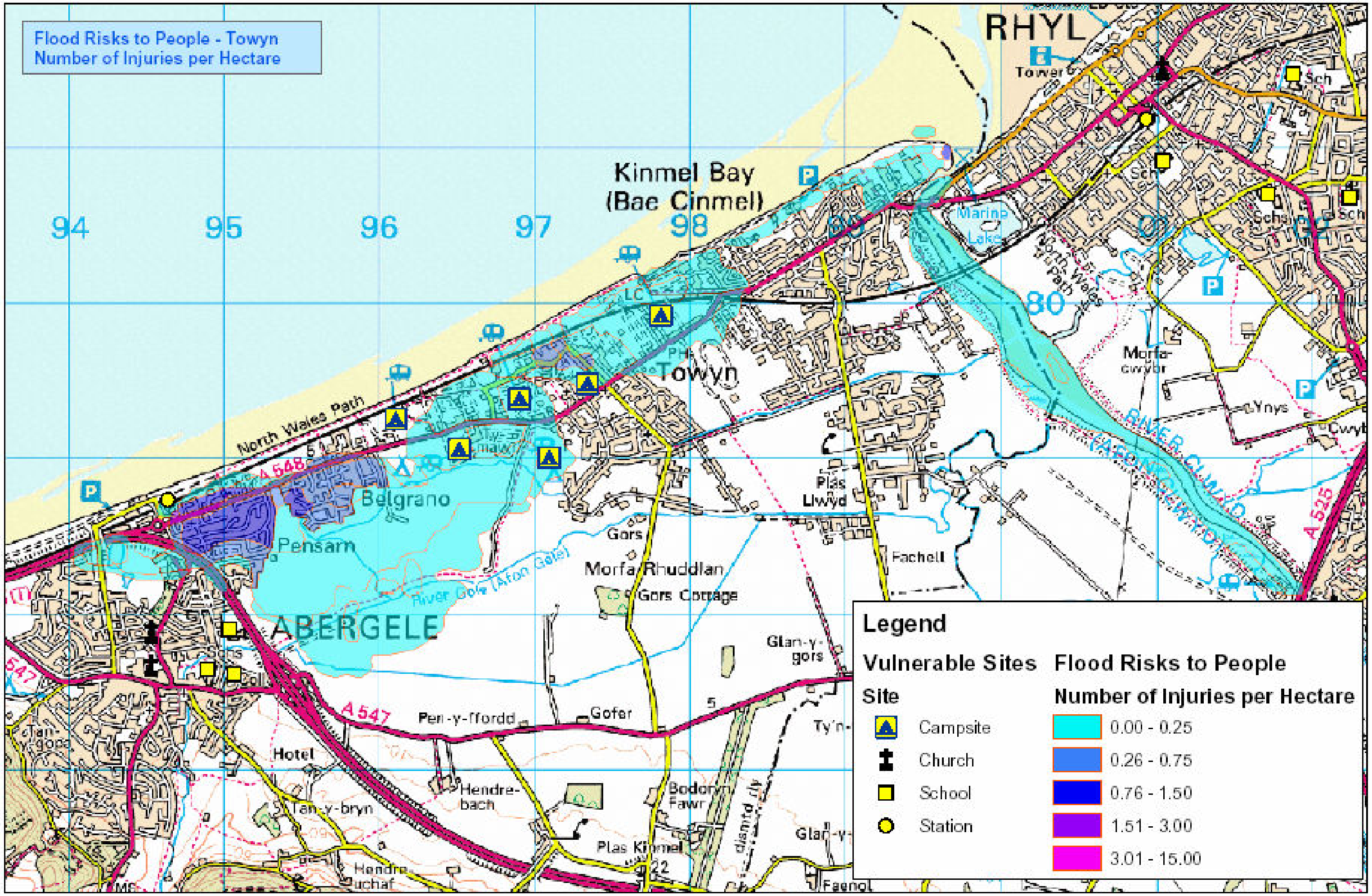

Flood Risk to People - Thamesmead
Number of Injuries per square kilometre
Legend
Vulnerable sites
Church
School
Number of Injuries/km2
0 - 10
11 - 25
26 - 100
101 - 1000
1000 - 3271
WOOLWICH
ERITH
Barking Reach
Halfway Reach
Gallions Reach
Erith Reach
HM Prison
Lesnes Abbey Woods

7.4.2 Towyn

Map 1 – An example of broad flood hazard zones. These were based of reviewing modelling output for a specific overtopping scenario. The zones can be digitised or derived using GIS processing of hydraulic model grids.
Map 2 – A flood hazard map for the same event.
Map 3 – The number of injuries per unit area. If the results from several larger events were combined then the map could show annual average societal risk. Note that in this case a larger area would need to be considered in order to include those affected by different flooding scenarios.


Flood Risks to People - Towyn Impact Zones
RHYL
Kinmel Bay
(Bae Cinmel)
Towyn
ABERGELE
North Wales Path
Belgrano
Pensarn
Morfa Rhuddlan
Gors Cottage
Glan-y-gors
Pen-y-ffordd
Gofer
Ty'n-y-llyn
Tytywyrch
Facholl
Plas Llwyd
Hafod-llwyn
Bryn-carrog Fm
Glan-y-morfa
Plas Kinmel
Hendre-bach
Tan-y-bryn
Hotel
Marine Lake
Morfa-cwybr
Ynys
A 547
A 525
A 548


Flood Risks to People - Towyn
Flood Hazard
RHYL
Kinmel Bay
(Bae Cinmel)
Towyn
Belgrano
Pensarn
ABERGELE
North Wales Path
Morfa Rhuddlan
Gors Cottage
Pen-y-ffordd
Gofer
Hotel
Tan-y-bryn
Glan-y-morfa
Plas Kinmel
Faenol
Facholl
Ynys
Legend
Vulnerable Sites
Site
Campsite
Church
School
Station
Flood Risks to People
Flood Hazard
Very Low
Low
Medium
High
Very High


Flood Risks to People - Towyn
Number of Injuries per Hectare
94
95
96
97
98
Kinmel Bay
(Bae Cinmel)
RHYL
Towyn
ABERGELE
Pensarn
Belgrano
North Wales Path
A 548
A 547
A 525
Morfa Rhuddlan
Gors Cottage
Gors
Glan-y-gors
Plas Llwyd
Fachell
Marine Lake
Morfa-cwybr
Ynys
River Clwyd (Afon Clwyd)
River Gele (Afon Gele)
Pen-y-ffordd
Gofer
Hotel
Tan-y-bryn
Hendre-bach
Hendre-uchaf
Plas Kinmel
Bodoryn Fawr
dismtd rly
Legend
Vulnerable Sites
Site
Campsite
Church
School
Station
Flood Risks to People
Number of Injuries per Hectare
0.00 - 0.25
0.26 - 0.75
0.76 - 1.50
1.51 - 3.00
3.01 - 15.00

8. CONCLUSIONS

Flooding from rivers, estuaries and the sea poses a risk to people as well as causing significant economic impacts. The Risks to People project developed a methodology for assessing and mapping the risk of death or serious harm to people caused by flooding.

Following the consideration of a large number of potential risks to people criteria and different versions of the flood hazard and overall risks to people formula, the final set of criteria required for the methodology are:-

Flood Hazard
- Depth of flood water (m)
- Velocity of flood water (m/s)
- Debris factor (score)

Area Vulnerability
- Flood warning: including % of at risk properties covered by flood warning system; % of warnings meeting two hour target; % of people taking effective action (score).
- Speed of onset (score)
- Nature of area: multi-storey apartments; typical residential/commercial/industrial properties; bungalows, mobile homes, campsites (score)

People Vulnerability
- % residents aged 75 years or over
- % residents suffering from long term illness

This report has provided an overview of the Risks to People method and several examples of its application. The mapping approach requires velocity and depth data for 5 flood events of different probabilities to estimate the annual average individual or societal risk. As such the methodology can be readily applied where these data are available.

In order to implement the full risks to people method nationally, a programme of flood hazard mapping is required that reviews and improves existing 1-D hydraulic models and develops the application of 2-D models that include a description of the defence system.

There are a number of areas of flood risk management where a simplified approach, involving the consideration of risks to people for the most extreme events only or developing component parts of the method would provide benefits, ensuring that these risks are considered alongside economic and environmental considerations. The accompanying guidance document (FD2321\TR2) provides information on how the method may be developed for different applications.

9. REFERENCES

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Requires additional of references from Phase 1.

Appendices

Appendix 1 Development of the flood hazard formula

This section describes background information of the development of the flood hazard formula, from the original flume experiments to comparison of the formula's and the decision to choose the final formula of:-

Flood hazard = depth x (velocity +0.5) + debris factor.

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

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

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

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

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

   where γ_w is the unit weight of water

3. the dynamic force due to velocity, P

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

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

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

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

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

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

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

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

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

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

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

RESCDAM, Helsinki University of Technology, 2000

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

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

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

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

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

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

$dv = 0.006hm + 0.3$ for good conditions
$dv = 0.004hm + 0.2$ for normal conditions
$dv = 0.002hm + 0.1$ for poor conditions.

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

Keller and Mitsch (1993)

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

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

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

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

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

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

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

Choice of flood hazard equations for final method

Consider how the degree of hazard varies with depth and velocity for four equations as shown in Table 3.1. To facilitate comparison across the different equations, 1.0m depth and 0.5 m/sec velocity has been used as the 'benchmark'.

Table 3.1 Equivalent Hazard Depths (m) for Different Hazard Rating Equations

Hazard Rating Equation	Velocity (m/sec)			
	0.1	0.5	1.0	2.0
HR = dv	5.00	1.00	0.50	0.25
HR = d(v+0.5)	1.67	1.00	0.67	0.40
HR = d(v+1.5)	1.25	1.00	0.80	0.57
HR = dv^2	25.00	1.00	0.25	0.06

By simple inspection, the dv^2 equations can be rejected as it places too greater an importance on velocity. Although the other three equations give similar results, the dv equation breaks down for slow moving floodwaters (as clearly flood depths of, say, 2m or more are hazardous whatever the velocity). Such arguments reinforce the need for a velocity adjustment factor if the variation in velocity (and depth) is to be reflected in the degree of associated hazard.

The question is which of the following statements is more credible?

- the degree of hazard associated with floodwaters moving at 0.1 m/sec and a depth approaching 1.7m is the same as that associated with floodwaters moving at 2.0 m/sec and a depth of 0.4m; or

- the degree of hazard associated with floodwaters moving at 0.1 m/sec and a depth of 1.25m is the same as that associated with floodwaters moving at 2.0 m/sec and a depth approaching 0.6m.

Clearly, these refer to the results of using HR = d(v+0.5) and HR = d(v+1.5) respectively, but the selection of the 'best' equation is, in part, dependent on the ultimate use of the equation. Given the potential range of uses of the outputs (i.e. apart from assisting with high level mapping), there is merit in exploring in a little more detail in how the degree of hazard varies in particular circumstances as outlined below.

Buildings

In broad terms, buildings are more resilient to floodwaters than people. Extensive research into this area has been undertaken by CURBE (see, for example, Kelman 2002). Further detail is provided in HR Wallingford *et at* (2004b) section 3 and HR Wallingford *et at* (2004c) section 2, but, as for people, the severity of damage is a function of both depth and velocity. However, as illustrated in Figure 3.1, there is only a poor relationship between damage level and the hazard rating expression derived for people (HR = d x (v +0.5). In other words, hazard function derived for people does not apply to buildings.

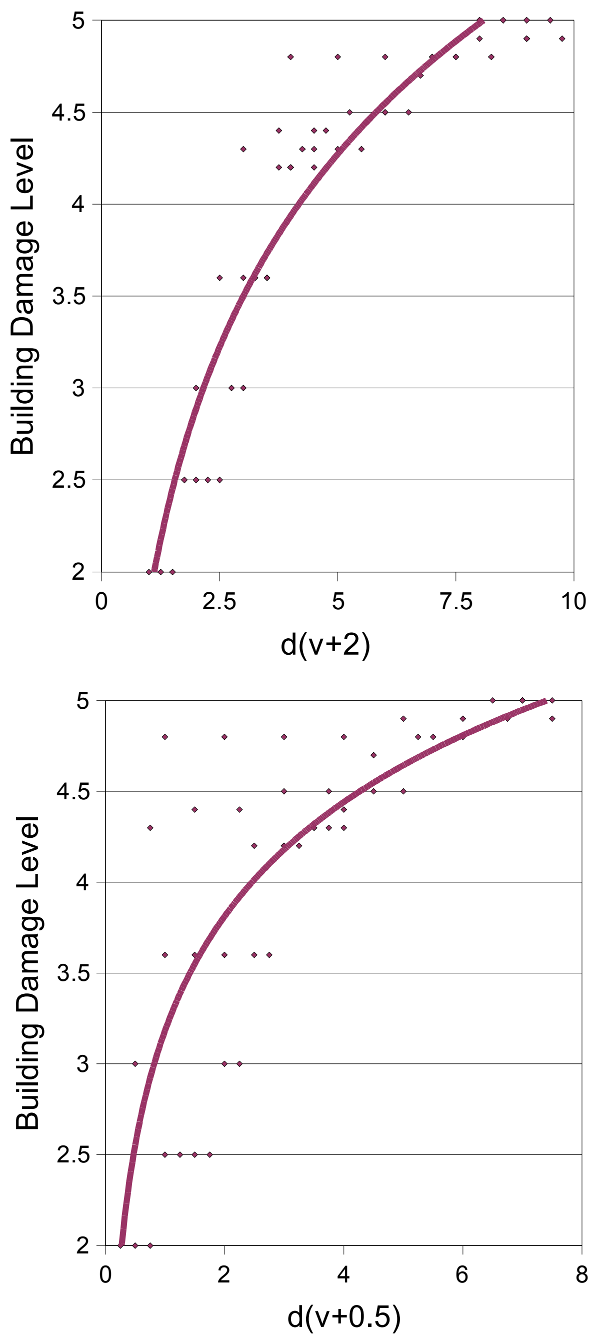

Figure 3.1 Variation of Building Damage with:
a) Depth/Velocity Function derived for People; and
b) an Improved Function (building damage is a function of d(v+2))

Appendix 2 Case Studies

This appendix includes case studies of flooding in Cliffe (Lewes), Hull and Tripcock Point on the Thames Estuary.

AQ.1 Case Study - Cliffe (Lewes)

AQ.1.1 Introduction

The Cliffe area of Lewes is bounded by the River Ouse to the west and south, by an elevated road (the Phoenix Causeway) to the north and by a steep hillside to the east. The area was badly flooded in October 2000 as illustrated in Figure AQ.1

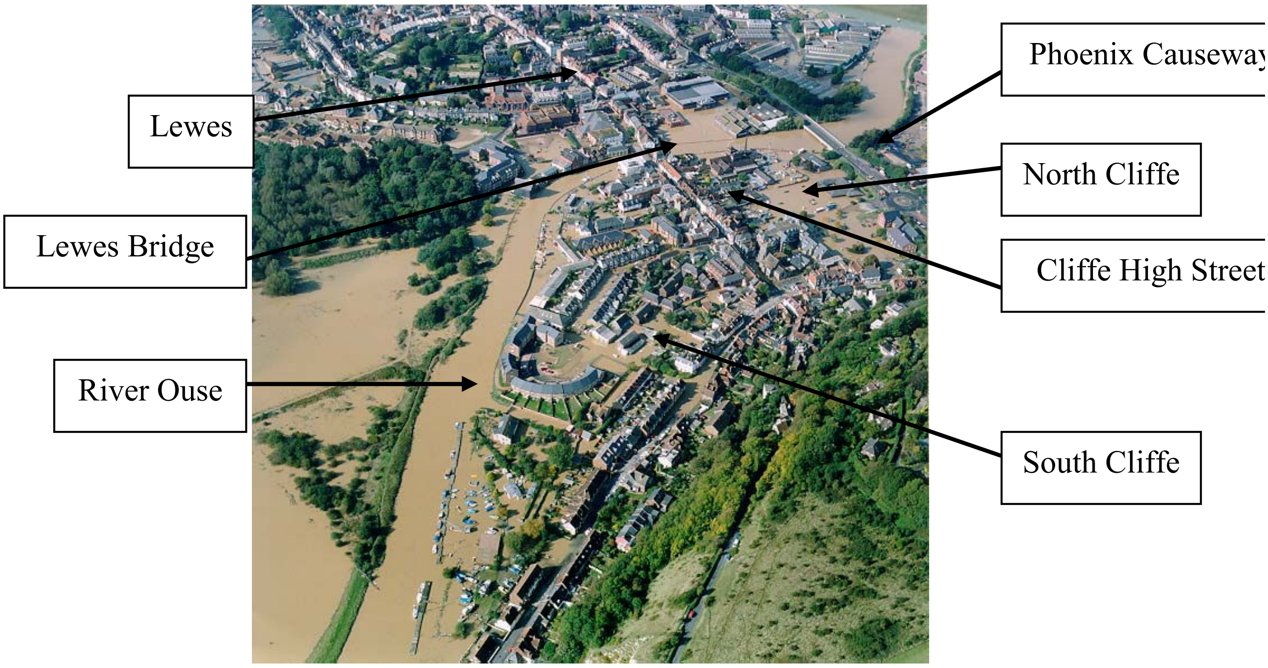

Figure AQ.1 View (looking NW) across Cliffe, October 2000 (reproduced from BBV, 2001)

The Cliffe area is defended by a substantial concrete wall with a height of about 4.75m. During the 200 floods, the highest flood levels were estimated to be about 5.5m to the north of Cliffe High Street and about 5.0m to the south of Cliffe High Street. These two areas are referred to as North Cliffe and South Cliffe in the calculations which follow.

The difference in flood levels was due, in part, to the river flow (north to south) being impeded by the Lewes Bridge.

AQ.1.2 Number of People at Risk

The existing defences have a standard approaching 1 in 100 years. Since the existing defences are substantial, the probability of a breach is considered to be negligible (in relation to the probabilities of overtopping considered in this analysis).

The numbers of properties at risk are summarised in Table AQ.1.

Table AQ.1: Number of Properties at Risk in Cliffe by Return Period

Area	Property Type	Return Period (years)		
		100	**160**	**200**
North Cliffe	Residential	27	+7	+5
	Non-residential	36	+1	+1
South Cliffe	Residential	139	+31	+21
	Non-residential	47	+5	+3
Cliffe	All (incremental)	249	+44	+30
	All (cumulative)	249	293	323

Sources: BBV (2001) and BBV (2002).

For a return period of 500 years, no further properties were assumed to be flooded (although the flood depth would be greater as indicated below).

Cliffe is located in the Lewes Bridge Ward which has an average of 2.1 people per household[6]. The majority of non-residential properties within Cliffe are shops (along the High Street). However, there is a number of larger non-residential properties (mainly close to the river) including Harveys brewery, Riverside Surgery and the local community centre (the Phoenix Centre) and boatyards. Although precise numbers have not been obtained, for the purposes of this analysis an average figure of 4 people per non-residential property will be assumed. Applying these factors to the numbers of properties at risk generates Table AQ.2.

Table AQ.2: Number of People at Risk (Nz) in Cliffe by Return Period

Area	Property Type	Return Period (years)		
		100	**160**	**200**
North Cliffe	Residential	57	+15	+10
	Non-residential	144	+5	+3
	All	**201**	**+20**	**+13**
South Cliffe	Residential	292	+66	+44
	Non-residential	188	+19	+13
	All	**480**	**+85**	**+56**
Cliffe	All (incremental)	681	+105	+70
	All (cumulative)	681	785	855

Source: Application of occupancy rates to Table AQ.1.

For a return period of 500 years, no further people were assumed to be at risk.

6 This and subsequent statistics for the Lewes Bridge Ward are based on data from the 2001 Census as obtained from http:\\neighbourhood.statistics.gov.uk (by entering a local postcode).

AQ.1.3 Hazard Rating

Flood Depth

Within Cliffe, road levels are generally in the region 4.2 to 4.6m. For this analysis, three hazard zones (in both North and South Cliffe) are considered:

- Zone A covers those properties at risk for a 1 in 100 year event with a typical floor level of around 4.3m;
- Zone B covers those properties at risk for a 1 in 160 year event with a typical floor level of around 4.6m; and
- Zone C covers those properties at risk for a 1 in 200 year event with a typical floor level of around 4.8m.

This information together with that observed in the 2000 floods as well as the estimated flood levels (from BBV, 2002) enabled Tables AQ.3 and AQ.4 to be constructed.

Table AQ.3: Flood Depths (d) by Hazard Zone in North Cliffe by Return Period

Area	Hazard Zone	Return Period (years) (Flood Level)			
	(Floor Level)	100 (5.2m)	160 (5.5m)	200 (5.8m)	500 (6.2m)
North Cliffe	A (4.3m)	0.9m	1.2m	1.5m	1.9m
	B (4.6m)	not affected	0.9m	1.2m	1.6m
	C (4.8m)	not affected	not affected	1.0m	1.4m

Source: Floor levels derived from information presented in Figure 4.9, BBV (2001) and flood levels derived from Appendix E, BBV (2002).

Table AQ.4: Flood Depths (d) by Hazard Zone in South Cliffe by Return Period

Area	Hazard Zone	Return Period (years) (Flood Level)			
	(Floor Level)	100 (4.8m)	160 (5.0m)	200 (5.2m)	500 (5.5m)
South Cliffe	A (4.3m)	0.5m	0.7m	0.9m	1.2m
	B (4.6m)	not affected	0.4m	0.6m	0.9m
	C (4.8m)	not affected	not affected	0.4m	0.7m

Source: As for previous table.

Note that flood levels are lower for South Cliffe as downstream of Lewes Bridge.

Flood Velocity

The detailed description of the flood events of October 2000 (BBV, 2001) indicates that the onset of flooding was fairly gradual (over a period of around three hours). Initially, drains backed up and this was followed by overtopping of the defences as the river increased in height. The build up of water upstream of the Lewes Bridge led to an increased flood level in North Cliffe. Although there were occasional 'break- throughs' with higher velocities, for the purposes of this analysis a general value for velocity, v, of 1.0 m/sec will be assumed.

Debris Factor

There were no reports of significant amounts of debris. On this basis, the debris factor (DF) has been taken as zero.

Hazard Rating

The equation for 'hazard rating', HR, is: HR = d x (v + 0.5) + DF

Substituting the values derived above enabled Table AQ.5 to be constructed.

Table AQ.5: Hazard Rating (HR) by Hazard Zone and by Return Period

Area	Hazard Zone	Return Period (years)			
		100	160	200	500
North Cliffe	A	1.4	1.8	2.3	2.9
	B	not affected	1.4	1.8	2.4
	C	not affected	not affected	1.5	2.1
South Cliffe	A	0.8	1.1	1.4	1.8
	B	not affected	0.6	0.9	1.4
	C	not affected	not affected	0.6	1.1

AQ.1.4 Area Vulnerability

Flood Warning

As detailed in the main text, the score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). For Southern Region, the 'generic' score is 2.14. Although the Agency claimed a high level of flood warning for Lewes (BBV, 2001), subsequent interviews with the flood victims indicated that only 33% of those flooded in Lewes reported receiving a warning[7]. On this basis, a relatively poor score for flood warning seems appropriate.

Speed of Onset

As already indicated, the speed of onset of flooding in Cliffe was 'gradual' which attracts a score of 2.

Nature of Area

As can be seen from Figure AQ.1, the Cliffe area is a typical mixed area of predominantly two-storey homes, commercial and industrial properties. This is a typical 'medium' risk area which attracts a score of 2.

[7] Based on responses from 159 residents affected by the 2000 floods in Lewes who were interviewed in relation to the work undertaken for RPA *et al* (2004).

Area Vulnerability Score

The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 6.14 (which indicates a medium risk area).

AQ.1.5 People Vulnerability

Long Term Illness

Based on statistics for the Lewes Bridge Ward, 16.3% of the Cliffe population have a limiting long-term illness (and/or disability).

The Very Old

Based on statistics for the Lewes Bridge Ward, 9.4% of the Cliffe population are 75 or over.

People Vulnerability Score

The people vulnerability (PV) score is simply the sum of the above factors to give PV = 25.7%. For comparison, the national figures are 18.2% and 7.6% respectively to give a combined score of 25.8%. As such, those at risk are no more vulnerable than the general population.

AQ.1.6 Numbers of Injuries and Fatalities.

Numbers of Injuries

For each hazard zone and each event, an estimate of the numbers of injuries (Ninj) can be made using the formula:

$$\text{Ninj} = 2 \times \text{Nz} \times \text{HR} \times \text{AV}/100 \times \text{PV}$$

The results are summarised in Tables AQ.6 and AQ.7 for North and South Cliffe respectively. This shows that for a 160 year event (similar to the 2000 floods), around 30 injuries would be expected in total with the majority occurring in South Cliffe.

Table AQ.6: Number of Injuries (Ninj) by Hazard Zone in North Cliffe and by Return Period

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		100	**160**	**200**	**500**
A	201	8.6	11.4	14.3	18.1
B	20	0.0	0.8	1.1	1.5
C	13	0.0	0.0	0.6	0.9
All	**234**	**9**	**12**	**16**	**20**

Table AQ.7: Number of Injuries (Ninj) by Hazard Zone in South Cliffe and by Return Period

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		100	**160**	**200**	**500**
A	480	11.4	15.9	20.4	27.3
B	85	0.0	1.6	2.4	3.6
C	56	0.0	0.0	1.1	1.9
All	**621**	**11**	**18**	**24**	**33**

Numbers of Injuries/Year

The average rate of injuries is based on both the numbers of injuries per event (i.e. as above) and the frequency of the events. Numerically, the numbers of injuries per year is:

$$\text{Ninj/per year} = \sum (\text{df} \times \text{Ninj})$$

The associated calculations are presented in Table AQ.8. For this analysis, it was assumed that no overflow of the defences occurred in a 1 in 60 year event.

Table AQ.8: Number of Injuries/Year by Hazard Zone

Return Period (years)	**500**	**100**	**160**	**200**	**500**	**All events**
Frequency (f) (per year)	1.7E-02	1.0E-02	6.3E-03	5.0E-03	2.0E-03	
Frequency interval (df)		6.7E-03	3.8E-03	1.3E-03	3.0E-03	
North Cliffe:						
Zone A (df x Ninj)	0	5.7E-02	4.3E-02	1.8E-02	5.4E-02	**1.7E-01**
Zone B (df x Ninj)	0	0.0E+00	3.2E-03	1.4E-03	4.5E-03	**9.1E-03**
Zone C (df x Ninj)	0	0.0E+00	0.0E+00	7.9E-04	2.6E-03	**3.4E-03**
South Cliffe:						
Zone A (df x Ninj)	0	7.6E-02	6.0E-02	2.6E-02	8.2E-02	**2.4E-01**
Zone B (df x Ninj)	0	0.0E+00	6.0E-03	3.0E-03	1.1E-02	**2.0E-02**
Zone C (df x Ninj)	0	0.0E+00	0.0E+00	1.3E-03	5.6E-03	**7.0E-03**

Numbers of Fatalities

For each hazard zone and each event, an estimate of the numbers of fatalities (Nf) can be made using the formula:

$$\text{Nf} = 2 \times \text{Ninj} \times \text{HR}/100$$

The results are summarised in Tables AQ.10 and AQ.11. The results indicate that one or two fatalities could be expected in Cliffe under the most severe conditions.

Table AQ.10: Number of Fatalities (Nf) by Hazard Zone and by Return Period (North Cliffe)

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		100	**160**	**200**	**500**
A	201	0.23	0.41	0.64	1.03
B	20	N/A	0.02	0.04	0.07
C	13	N/A	N/A	0.02	0.04
All	**234**	**0.2**	**0.4**	**0.7**	**1.1**

Table AQ.11: Number of Fatalities (Nf) by Hazard Zone and by Return Period (South Cliffe)

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		100	**160**	**200**	**500**
A	480	0.17	0.33	0.55	0.98
B	85	N/A	0.02	0.04	0.10
C	56	N/A	N/A	0.01	0.04
All	**621**	**0.2**	**0.4**	**0.6**	**1.1**

Numbers of Fatalities/Year

In the same way as for injuries, the average rate of fatalities is based on both the numbers of fatalities per event (i.e. as above) and the frequency of the events. Numerically, the numbers of fatalities per year is:

$$Nf/\text{per year} = \sum (df \times Nf)$$

The associated calculations are presented in Table AQ.12. As before, it was assumed that no overflow of the defences occurred in a 1 in 60 year event.

Table AQ.12: Number of Fatalities/Year by Hazard Zone

Return Period (years)	**60**	**100**	**160**	**200**	**500**	**All events**
Frequency (f) (per year)	1.7E-02	1.0E-02	6.3E-03	5.0E-03	2.0E-03	
Frequency interval (df)		6.7E-03	3.8E-03	1.3E-03	3.0E-03	
North Cliffe:						
Zone A (df x Nf)	0	1.5E-03	1.5E-03	8.0E-04	3.1E-03	**7.0E-03**
Zone B (df x Nf)	0	0.0E+00	8.6E-05	5.1E-05	2.2E-04	**3.5E-04**
Zone C (df x Nf)	0	0.0E+00	0.0E+00	2.4E-05	1.1E-04	**1.3E-04**
South Cliffe:						
Zone A (df x Nf)	0	1.1E-03	1.3E-03	6.9E-04	2.9E-03	**6.0E-03**
Zone B (df x Nf)	0	0.0E+00	7.2E-05	5.4E-05	2.9E-04	**4.2E-04**
Zone C (df x Nf)	0	0.0E+00	0.0E+00	1.6E-05	1.2E-04	**1.3E-04**

AQ.1.7 Measures of Risk & Acceptability

Introduction

For mapping purposes, consideration is given to two measures of risk:

- societal risk - where this is represented by the average numbers of injuries per year per square kilometre; and
- individual risk - where this is represented by the average level of risk amongst those at risk.

These measures enable some conclusions to be drawn to the acceptability of the risk and the implications for land-use planning.

Societal Risk

The measure of societal risk = 100 x Ninj/year / Zone Area (ha) = Ninj/year/km^2

The associated calculations are summarised in Table AQ.13.

Table AQ.13: Cliffe Societal Risk Calculations

Area	Zone	Ninj/year	Area (ha)	Ninj/yr/ha	Ninj/yr/km^2
North Cliffe	A	1.7E-01	3.6	4.8E-02	**4.8**
	B	9.1E-03	0.4	2.6E-02	**2.6**
	C	3.4E-03	0.2	1.4E-02	**1.4**
South Cliffe	A	2.4E-01	5.0	4.8E-02	**4.8**
	B	2.0E-02	0.9	2.2E-02	**2.2**
	C	7.0E-03	0.6	1.2E-02	**1.2**

Source: Ninj/year from Table AQ.8 and areas by zone based on a pro-rate distribution (by population at risk) of estimated total areas of 4.2 and 6.5 ha for North and South Cliffe respectively.

Individual Risk

The average individual risk (by zone) = Nf/year / Number of people at risk (Nz)

The associated calculations are summarised in Table AQ.14.

Table AQ.14: Cliffe Individual Risk Calculations

Area	Zone	Nf/year	Nz	Individual Risk
North Cliffe	A	7.0E-03	201	3.5E-05
	B	3.5E-04	20	1.8E-05
	C	1.3E-04	13	1.0E-05
South Cliffe	A	6.0E-03	480	1.3E-05
	B	4.2E-04	85	4.9E-06
	C	1.3E-04	56	2.4E-06

Source: Nf/year from Table AQ.12 and Nz from Tables AQ.10 and AQ.11.

Acceptability of Individual Risk

The level of individual risk (IR) within three zones in North Cliffe and two zones in South Cliffe is above the suggested risk criterion of 1 chance in 100,000 (1.0E-05) per year of being killed in a flood event. As such the general level of risk would not be regarded as tolerable.

Application of Societal Risk Criterion

The proposed societal risk criterion is that: *the number at risk x level of individual risk* $< 1 \times 10^{-3}$ *per year*. As such, the maximum number at risk should be less than 1.0E-03/individual risk. The results of applying this criterion are shown in Table AQ.15.

Table AQ.15: Determination of Maximum Numbers of People

Area	Parameter	Zone A	Zone B	Zone C
North Cliffe	Level of individual risk (100% occupancy)	3.5E-05	1.8E-05	1.0E-05
	Maximum number of people permitted	29	56	99
	Maximum number of houses permitted	12	23	40
South Cliffe	Level of individual risk (100% occupancy)	1.3E-05	4.9E-06	2.4E-06
	Maximum number of people permitted	80	202	422
	Maximum number of houses permitted	32	81	169

Resultant Planning Advice (based on Risk Criteria)

Application of the risk criteria results in the advice summarised in Tables AQ.16 and AQ.17.

Table AQ.16: Planning Advice based on Risk Criteria for North Cliffe

Risk Criterion	Area A	Area B	Area C
Individual Risk	Residential development not permitted		Residential development permitted
	Industrial/commercial development permitted		
Societal Risk	Maximum of 29 people (12 houses)	Maximum of 56 people (23 houses)	Maximum of 99 people (40 houses)
Resultant Planning Advice	No new residential development permitted. Limited industrial/ commercial development permitted but no more than 29 people at risk at any one time.	No new residential development permitted. Limited industrial/ commercial development permitted but no more than 56 people at risk at any one time.	Residential development permitted (up to 40 houses). Alternatively, industrial/commercial development permitted but no more than 99 people at risk at any one time.

Note: For Zone A, for non-residential development, an occupancy factor of 0.25 is incorporated which leads to an individual risk of 3.5E-05 x 0.25 = 8.7E-06 per year which is below the suggested target of 1.0E-05 per year. For Zone B, the individual risk is correspondingly lower.

Table AQ.17: Planning Advice based on Risk Criteria for South Cliffe

Risk Criterion	Area A	Area B	Area C
Individual Risk	Residential development not permitted	Residential development permitted	
	Industrial/commercial development permitted		
Societal Risk	Maximum of 80 people (32 houses)	Maximum of 202 people (81 houses)	Maximum of 422 people (169 houses)
Resultant Planning Advice	No new residential development permitted. Limited industrial/ commercial development permitted but no more than 80 people at risk at any one time.	Residential development permitted (up to 81 houses). Alternatively, industrial/commercial development permitted but no more than 202 people at risk at any one time.	Residential development permitted (up to 169 houses). Alternatively, industrial/commercial development permitted but no more than 422 people at risk at any one time.

For Zone A, the incorporation of an occupancy factor for non-residential use reduces the level of individual risk to below the suggested target value of 1.0E-05 per year

AQ.1.8 References

Binnie Black & Veatch (2001): **Sussex Ouse 12th October 2000 Flood Report**, report prepared for the Environment Agency, dated March 2001.

Binnie Black & Veatch (2002): **Sussex Ouse Flood Management Strategy - Project Appraisal Report: Volume 2 - Appendices B to P**, report prepared for the Environment Agency, dated July 2002.

RPA *et al* (2004): **The Appraisal of Human-Related Intangible Impacts of Flooding**, Defra/EA R&D Technical Report FD2005/TR, dated August 2004.

AQ.2 Case Study - Hull

AQ.2.1 Introduction

Hull is situated on the north bank of the Humber. Although there are defences, the standard of protection is low. However, the main trunk route (the A63) which runs close to the river provides substantial secondary defences.

In this example consideration is given to the riverside area immediately to the south-west of city centre. This area forms parts of Flood Cell 2-2 considered in the development of Humber Strategy (being undertaken by BBV for the Agency).

The area is at risk, primarily, from overtopping of the defences and is bounded to the north-west by the A63 and to the south-east by the Humber. Two zones (each of approximately 25ha in area) are considered in this analysis and are illustrated in Figure AQ.2.

- Zone A forms the western part is a mixture of industrial and commercial premises, including a number of warehouses and bulk storage areas; and
- Zone B is the recently redeveloped area around the Hull Marina and comprises a mixture of residential, industrial and commercial properties.

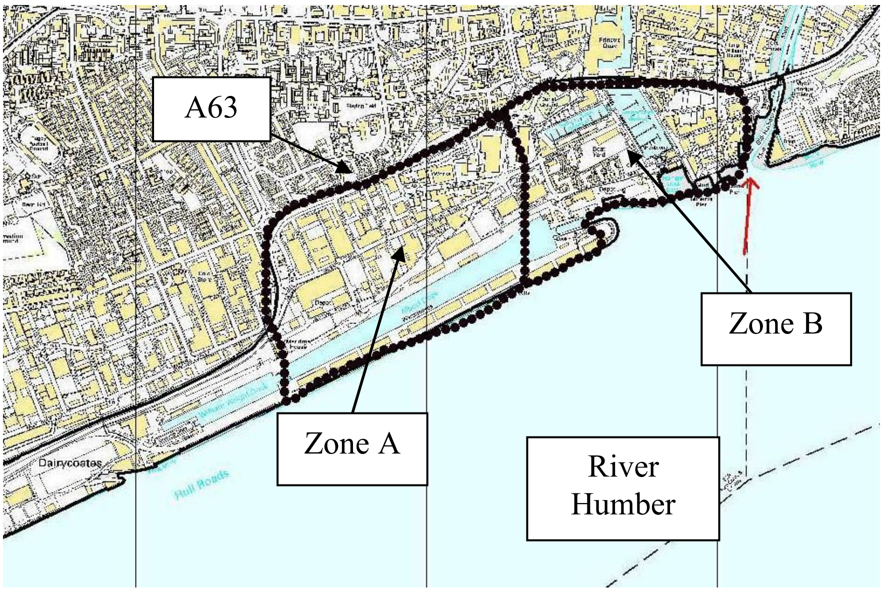

Figure AQ.2 Areas Considered in Analysis from Flood Cell 2-2 (reproduced from BBV, 2004)

AQ.2.2 Number of People at Risk

The numbers of properties at risk are summarised in Table AQ.18. Since the area under consideration is effectively a 'basin' (once the defences are overtopped), the numbers of properties affected are the same for each of the return periods considered (although the depth of flooding varies).

Table AQ.18: Numbers of Properties at Risk in Hull (part of Flood Cell 2-2)

Property Type	**Zone A**	**Zone B**
Residential	**5**	**354**
Industrial/Commercial	**170**	**152**
- *factories*	*16*	*1*
- *retail*	*21*	*25*
- *office*	*11*	*47*
- *warehouse*	*93*	*39*
- *'all bulk' (storage areas)*	*29*	*40*
Total	**175**	**506**

Source: Based on spreadsheets prepared by Black & Veatch for the economic appraisal of options under consideration in the Humber Estuary Flood Defence Strategy (HEFDS).

The area is located in the Myton Ward (of Hull) which has an average of 1.8 people per household[8]. As illustrated in the table above, there are a range of non-residential properties. These range from properties with low staff numbers (such as warehouses and storage areas) to large retail shops and offices. Although precise numbers have not been obtained, for the purposes of this analysis an average figure of 4 people per non-residential property will be assumed. Applying these factors to the numbers of properties at risk generates Table AQ.19.

Table AQ.19: Numbers of People at Risk in Hull (part of Flood Cell 2-2)

Property Type	**Zone A**	**Zone B**
Residential	9	637
Industrial/Commercial	680	608
All	689	1245

Source: Application of occupancy rates to Table AQ.18.

AQ.2.3 Hazard Rating

Flood Depth

The detailed spreadsheets prepared for the HEFDS include the predicted flood depths for each property by return period. For properties in Zones A and B, these depths have been averaged to enable Table AQ.20 to be prepared.

8 This and subsequent statistics for the Myton Ward are based on data from the 2001 Census as obtained from http:\\neighbourhood.statistics.gov.uk (by entering a local postcode).

Table AQ.20: Flood Depths (d) by Hazard Zone in Hull by Return Period

Hazard Zone	Return Period (years) (Flood Level)			
(Floor Level)	10 (5.12m)	50 (5.29m)	100 (5.35m)	500 (5.50m)
A (2.46m)	2.66	2.83	2.89	3.04
B (4.28m)	0.84	1.01	1.07	1.22

Source: Floor levels derived from information in HEFDS spreadsheets for damage calculations.

Flood Velocity

It is envisaged that the flooding of the area under consideration will be fairly gradual (in much the same way as for Cliffe considered previously). For the purposes of this analysis a general value for velocity, v, of 1.0 m/sec will be assumed.

Debris Factor

For the purpose of this analysis, the debris factor (DF) has been taken as zero.

Hazard Rating

The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above enabled Table AQ.21 to be constructed.

Table AQ.21: Hazard Rating (HR) by Hazard Zone and by Return Period

Hazard Zone	Return Period (years)			
	10	50	100	500
A	4.0	4.3	4.3	4.6
B	1.3	1.5	1.6	1.8

AQ.2.4 Area Vulnerability

Flood Warning

As detailed in the main text, the score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). The North East region has made most progress in achieving the targets and the 'generic' score for Yorkshire and Humber is 1.73 and this score is used in the analysis which follows.

Speed of Onset

The speed of onset of flooding has been assumed to be 'gradual' which attracts a score of 2.

Nature of Area

The area of Hull under consideration is mixed with homes, commercial and industrial properties. As such, this is considered to be a 'medium' risk area which attracts a score of 2.

Area Vulnerability Score

The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 5.73 (which indicates a medium risk area).

AQ.2.5 People Vulnerability

Local Statistics

Based on statistics for the Myton Ward, 29.4% of the population have a limiting long-term illness (and/or disability) and 9.1% of the population are 75 or over (and, for comparison, the national figures are 18.2% and 7.6% respectively).

Selected Values

However, the figures for Myton Ward generally are not considered suitable for Zones A and B. From Table AQ.18, it is clear that Zone A is an industrial/ commercial area with some retail outlets. With this in mind, it would be expected that the proportion of people with a limiting long-term illness and/or over 75 would be substantially less than the ward figures suggest. For the purposes of this analysis, values of 5% for both long term illness and the 75s and over will be used for Zone A.

Zone B is a mixed area (see Table AQ.18) and is likely to contain a greater proportion of both groups of people vulnerable to flooding than Zone A. However, the figures are unlikely to be as high as those suggested by the ward statistics taking account of both the non-residential uses in the area and marine style residential development. With these points in mind, values of 10% for long term illness and 7.5% for the 75s and over will be used for Zone B.

People Vulnerability

The people vulnerability (PV) score is simply the sum of the above factors to give PV = 10.0% and 17.5% for Zones A and B respectively. As such, those at risk are less vulnerable than the general population (since the PV value would be 25.8% based on national statistics).

AQ.2.6 Numbers of Injuries and Fatalities.

Numbers of Injuries

For each hazard zone and each event, an estimate of the numbers of injuries (Ninj) can be made using the formula:

$$\text{Ninj} = 2 \times \text{Nz} \times \text{HR} \times \text{AV}/100 \times \text{PV}$$

The results are summarised in Tables AQ.22. This shows, for example, that for a 50 year event, around 60 injuries would be expected in total with the majority occurring in Zone B.

Table AQ.22: Number of Injuries (Ninj) by Hazard Zone and by Return Period

Hazard Zone	**No. at Risk (Nz)**	**Return Period (years)**			
		10	**50**	**100**	**500**
A	689	21.0	22.4	22.9	24.0
B	1245	31.4	37.7	40.0	45.6
All	**1934**	**52**	**60**	**63**	**70**

Numbers of Injuries/Year

The average rate of injuries is based on both the numbers of injuries per event (i.e. as above) and the frequency of the events. Numerically, the numbers of injuries per year is:

$$\text{Ninj/per year} = \sum (\text{df} \times \text{Ninj})$$

The associated calculations are presented in Table AQ.23. For this analysis, it was assumed that no overflow of the defences occurred in a 1 in 5 year event.

Table AQ.23: Number of Injuries/Year by Hazard Zone

Return Period (years)	**5**	**10**	**50**	**100**	**500**	**All events**
Frequency (f) (per year)	2.0E-01	1.0E-01	2.0E-02	1.0E-02	2.0E-03	
Frequency interval (df)		1.0E-01	8.0E-02	1.0E-02	8.0E-03	
Zone A (df x Ninj)	0	2.10	1.79	0.23	0.19	**4.3**
Zone B (df x Ninj)	0	3.14	3.02	0.40	0.36	**6.9**

Numbers of Fatalities

For each hazard zone and each event, an estimate of the numbers of fatalities (Nf) can be made using the formula:

$$\text{Nf} = 2 \times \text{Ninj} \times \text{HR}/100$$

The results are summarised in Tables AQ.24. The results indicate that a few fatalities would be expected in the more severe events.

Table AQ.24: Number of Fatalities (Nf) by Hazard Zone and by Return Period

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		10	**50**	**100**	**500**
A	689	1.7	1.9	2.0	2.2
B	1245	0.8	1.1	1.3	1.7
All	**1934**	**2.5**	**3.0**	**3.3**	**3.9**

Numbers of Fatalities/Year

In the same way as for injuries, the average rate of fatalities is based on both the numbers of fatalities per event (i.e. as above) and the frequency of the events. Numerically, the numbers of fatalities per year is:

$$Nf/\text{per year} = \sum (df \times Nf)$$

The associated calculations are presented in Table AQ.25. As before, it was assumed that no overflow of the defences occurred in a 1 in 5 year event.

Table AQ.25: Number of Fatalities/Year by Hazard Zone

Return Period (years)	5	10	50	100	500	All events
Frequency (f) (per year)	2.0E-01	1.0E-01	2.0E-02	1.0E-02	2.0E-03	
Frequency interval (df)		1.0E-01	8.0E-02	1.0E-02	8.0E-03	
Zone A (df x Nf)	0	1.7E-01	1.5E-01	2.0E-02	1.8E-02	**3.6E-01**
Zone B (df x Nf)	0	7.9E-02	9.1E-02	1.3E-02	1.3E-02	**2.0E-01**

AQ.2.7 Measures of Risk & Acceptability

Introduction

For mapping purposes, consideration is given to two measures of risk:

- societal risk - where this is represented by the average numbers of injuries per year per square kilometre; and
- individual risk - where this is represented by the average level of risk amongst those at risk.

These measures enable some conclusions to be drawn to the acceptability of the risk and the implications for land-use planning.

Societal Risk

The measure of societal risk = 100 x Ninj/year / Zone Area (ha) = Ninj/year/km^2

The associated calculations are summarised in Table AQ.26.

Table AQ.26: Societal Risk Calculations

Zone	Ninj/year	Area (ha)	Ninj/yr/ha	Ninj/yr/km^2
A	4.3	25	0.17	17
B	6.9	25	0.28	28

Source: Ninj/year from Table AQ.23 and areas provided in AQ.2.1.

Individual Risk

The average individual risk (by zone) = Nf/year / Number of people at risk (Nz)

The associated calculations are summarised in Table AQ.27.

Table AQ.27: Individual Risk Calculations

Zone	Nf/year	Nz	Individual Risk
A	3.6E-01	689	5.2E-04
B	2.0E-01	1245	1.6E-04

Source: Nf/year from Table AQ.25 and Nz from Table AQ.24.

Acceptability of Individual Risk

The level of individual risk (IR) within both Zone A and Zone B is above the suggested risk criterion of 1 chance in 100,000 (1.0E-05) per year of being killed in a flood event. As such the level of risk is not considered to be tolerable for new development.

Application of Societal Risk Criterion

The proposed societal risk criterion is that: *the number at risk x level of individual risk < 1 x 10^{-3} per year*. As such, the maximum number at risk should be less than 1.0E-03/individual risk. The results of applying this criterion are shown in Table AQ.28.

Table AQ.28: Determination of Maximum Numbers of People

Parameter	Zone A	Zone B
Level of individual risk (100% occupancy)	5.2E-04	1.6E-04
Maximum number of people permitted	2	6
Maximum number of houses permitted	1	3

Resultant Planning Advice (based on Risk Criteria)

Application of the risk criteria results in the advice summarised in Tables AQ.29.

Table AQ.29: Planning Advice based on Risk Criteria

Risk Criterion	Area A	Area B
Individual Risk	Residential development not permitted Industrial/commercial development not permitted	
Societal Risk	Maximum of 2 people (1 house)	Maximum of 6 people (3 houses)
Resultant Planning Advice	No new development permitted.	

Note: For non-residential development, incorporating an occupancy factor of 0.25 would still lead to levels of individual risk greater than the suggested target of 1.0E-05 per year.

AQ.2.8 References

Black & Veatch (2004): **Humber Estuary Flood Defence Strategy - Management Units and Flood Compartment Boundaries**, drawing prepared for the Environment Agency, dated November 2004.

AQ.3 Case Study - Tripcock Point (Thamesmead)

AQ.3.1 Introduction

Tripcock Point (Thamesmead) is a major planned development which forms part of the Thames Gateway. It is located on the south bank of the River Thames to the east of London (and downstream of the Thames Barrier).

The 34ha site is bounded to the north by the Thames, to the east by the Thamesmead Centre and to the west by Tripcock Park. The proposals are for 2000 dwellings (on 25ha of the site) together with some ground floor commercial properties (offices, shops, cafes, etc.). The proposed layout is shown in Figure AQ.3.

Figure AQ.3 Proposed Layout of Tripcock Point (reproduced from Tilfen Land, 2003)

Three zones are considered in this analysis:

- Zone A (9.5 ha in size) forms the south-eastern part of the site. This zone is bounded by the 3m contour and is mostly (relatively) low density housing;
- Zone B (6.5 ha in size) forms the central part of the site. This zone is bounded by the 3 and 5.5m contours and is mostly medium density housing and some ground floor commercial premises (around the central roundabout); and

- Zone C (18 ha) forms the northern and north-western part of the site and is above the 5.5m contour. This zone comprises high and medium density housing including commercial premises along the riverfront.

AQ.3.2 Number of People at Risk

Estimates of the numbers of dwellings, dwellings with ground floor accommodation and commercial properties have been based on the information presented in the Planning Statement (Tilfen Land, 2003) using the following assumptions:

- dwellings in low density areas are all assumed to have ground floor accommodation;
- 50% of units in medium density areas are assumed to have ground floor accommodation;
- 25% of units on high density areas are assumed to have ground floor accommodation; and
- for those areas with designated commercial uses (E1 to E4 and C8 to C11), 50% of ground floor units area assumed to be non-residential.

Whilst these are assumptions, they provide a basis for the analysis which follows to illustrate the application of the methodologies that have been developed.

Table AQ.30: Numbers of Properties by Zone for Tripcock Point

Parameter	Zone A	Zone B	Zone C
Number of dwellings by zone	354	267	1378
Number of units with ground floor accommodation	256	160	514
Number of dwellings with ground floor accommodation	256	130	446
Number of ground floor commercial premises	0	30	68

Source: Based on layout presented in Figure AQ.3 and assumptions listed above.

Tripcock Point is located in the Thamesmead Moorings Ward which has an average of 2.3 people per household[9]. As illustrated in the table above, there are a range of non-residential properties. These will be generally relatively small units (shops and offices) and for the purposes of this analysis an average figure of 4 people per non-residential property will be assumed. Applying these factors to the numbers of properties at risk generates Table AQ.31.

Table AQ.31: Numbers of People by Zone for Tripcock Point

Property Type	Zone A	Zone B	Zone C
Residential	590	300	1026
Commercial	0	119	273
All	590	419	1299

Source: Based on Table AQ.30 and occupancy rates given above.

9 This and subsequent statistics for the Thamesmead Moorings Ward are based on data from the 2001 Census as obtained from http:\\neighbourhood.statistics.gov.uk (by entering a local postcode).

AQ.3.3 Hazard Rating

Introduction

Tripcock Point has been subject to a flood risk assessment (FRA). The report (Scott Wilson, 2004) considers scenarios involving overtopping of the defences, overflowing of the defences and breach of the defences. The most significant risk is associated with overflowing in which extreme water levels (at the peak of high tide) lead to a large flow of water over the defences (which are 7.1m in height). The water flows over the site and collects in the south-eastern part of the site. The FRA focuses on the 1000 year event in 2060 incorporating sea level rise. For the purpose of this analysis, the following extreme water level probabilities have been assumed.

Table AQ.32: Extreme Water Heights (m ODN) by Return Period at Tripcock Point

Return Period	for 2030	for 2060 with Sea Level Rise
750 years	7.00m	7.30m
1000 years	7.10m(1)	7.40m(2)
1500 years	7.25m	7.55m
2000 years	7.35m	7.65m

Notes:

1) The defences along the Thames are currently based on the predicted water levels for a 1 in 1,000 event in 2030 (i.e. 7.1m at Tripcock Point)

2) The FRA is based on this 1 in 1,000 year event for the 2060 scenario with further sea level rise

Sources: Scott Wilson (2004) for base case of 1 in 1,000 years and related information from the Environment Agency.

Flood Depth

The FRA provides spreadsheets (with particular reference to Appendix G) detailing the calculations used to derive not only flood depths on the south-eastern part of the site (in a 1 in 1,000 year event) but also the depth (and velocity) of water flowing across the site. As would be expected, the peak depths (and velocities) for the flowing water occur at the peak of high tide whereas the peak depth for the flooded areas occur about one hour later[10]. These calculations have been extended to the other return periods listed in Table AQ.32 and the results are summarised in Table AQ.33.

[10] The flood level then drops due to the fall in water level in the river and as the pumps 'catch up' with the floodwaters.

Table AQ.33: Flood Depths (d) by Hazard Zone by Return Period

Hazard Zone	Return Period (years) (Peak Water Level)			
(Ground Level)	750 (7.30m)	1,000 (7.40m)	1,500 (7.55m)	2,000 (7.65m)
A (<3m)	0.09m (flowing) 0.00m (still)	0.11m (flowing) 0.75m (still)	0.15m (flowing) 3.25m (still)	0.17m (flowing) 4.85m (still)
B (3 - 5.5m)	0.09m (flowing) 0.00m (still)	0.11m (flowing) 0.00m (still)	0.15m (flowing) 1.25m (still)	0.17m (flowing) 2.85m (still)
C (>5.5m)	0.09m (flowing) 0.00m (still)	0.11m (flowing) 0.00m (still)	0.15m (flowing) 0.00m (still)	0.17m (flowing) 0.7m (still)

Flood Velocity

For the areas which are flooded, a relatively low flood velocity of 0.5 m/sec has been assumed. For the flowing waters, the velocities have been calculated based on the information presented in the FRA.

Table AQ.34: Flood Velocities by Hazard Zone in Tripcock Point by Return Period

Hazard Zone	Return Period (years)			
	750	1,000	1,500	2,000
All	1.53 m/sec	2.16 m/sec	3.05 m/sec	3.60 m/sec

Source: Based on calculations presented in Appendix G, FRA (Scott Wilson, 2004).

Debris Factor

For the purpose of this analysis, the debris factor (DF) (for flowing waters only) has been taken as zero for the 750 year event, as 0.5 for the 1,000 year event and 1 for the more extreme events. It is considered that under the relatively high velocities for the more extreme events, significant amounts of debris would be expected to be carried by the floodwaters.

Hazard Rating

The equation for 'hazard rating', HR, is: $HR = d \times (v + 0.5) + DF$

Substituting the values derived above enabled Table AQ.35 to be constructed for both flowing waters and still waters. The hazard rating selected for further analysis was taken as the maximum of these two values.

Table AQ.35: Hazard Rating (HR) by Hazard Zone and by Return Period

Hazard Zone	Return Period (years)			
	750	1,000	1,500	2,000
All (flowing)	0.18	0.80	1.53	1.70
A (still)	0.00	0.75	3.25	4.85
B (still)	0.00	0.00	1.25	2.85
C (still)	0.00	0.00	0.00	0.70
A (max)	0.18	0.80	3.25	4.85
B (max)	0.18	0.80	1.53	2.85
C (max)	0.18	0.80	1.53	1.70

AQ.3.4 Area Vulnerability

Flood Warning

As detailed in the main text, the score for flood warning is on the scale 1 (good warning system) to 3 (no warning system). For this case study, it will be assumed that given the importance of flood warnings for the River Thames, the Agency has met all of its targets (by 2060) in respect of flood warning. On this basis, a flood warning score of 1 has been awarded.

Speed of Onset

For the Thames Estuary, there will be many hours warning of an imminent extreme high tide and the flooding of the south-eastern part of the site will take place over a few hours (i.e. during the peak of the tide cycle). On this basis, the speed of onset[11] of flooding is assumed to be 'gradual' which attracts a score of 2.

Nature of Area

Based on a consideration of the distribution of properties by hazard zone, Zone A is considered to be a typical medium risk residential area which attracts a score of 2. Zone B is a mixed area with medium density housing (including some apartments) and commercial uses which, again, is assigned a score of 2. Zone C is a mix of high./medium density housing including many multi-storey apartment blocks. On this basis, Zone C is considered to be a low risk area which attracts a score of 1.

Area Vulnerability Score

The Area Vulnerability (AV) score is then the sum of the above factors to give AV = 5 for Zones A and B and 4 for Zone C.

AQ.3.5 People Vulnerability

Long Term Illness

Based on statistics for the Thamesmead Moorings Ward (of Greenwich), 14.5% of the population have a limiting long-term illness (and/or disability).

The Very Old

Based on statistics for the Thamesmead Moorings Ward, only 2.7% of the population are 75 or over.

[11] Note that the 'speed' of onset is not the same as the 'speed' of the flood waters (which has already been considered above 'flood velocity').

People Vulnerability Score

The people vulnerability (PV) score is simply the sum of the above factors to give PV = 17.2%. For comparison, the national figures are 18.2% and 7.6% respectively to give a combined score of 25.8%. As such, those at risk are less vulnerable than the general population.

AQ.3.6 Numbers of Injuries and Fatalities.

Numbers of Injuries

For each hazard zone and each event, an estimate of the numbers of injuries (Ninj) can be made using the formula:

$$\text{Ninj} = 2 \times \text{Nz} \times \text{HR} \times \text{AV}/100 \times \text{PV}$$

The results are summarised in Table AQ.36. This shows that for the 750 year event, only 7 injuries would be expected, whilst for the 2,000 year event over 100 injuries would be expected.

Table AQ.36: Number of Injuries (Ninj) by Hazard Zone and by Return Period

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		750	1,000	1,500	2,000
A	590	1.8	8.1	33.0	49.2
B	419	1.3	5.8	11.0	20.5
C	1299	4.0	17.9	34.2	37.9
All	**2308**	**7**	**32**	**78**	**108**

Numbers of Injuries/Year

The average rate of injuries is based on both the numbers of injuries per event (i.e. as above) and the frequency of the events. Numerically, the numbers of injuries per year is:

$$\text{Ninj/per year} = \sum (\text{df} \times \text{Ninj})$$

The associated calculations are presented in Table AQ.37. For this analysis, it was assumed that no overflow of the defences occurred in a 1 in 500 year event.

Table AQ.37: Number of Injuries/Year by Hazard Zone

Return Period (years)	500	750	1,000	1,500	2,000	All events
Frequency (f) (per year)	2.0E-03	1.3E-03	1.0E-03	6.7E-04	5.0E-04	
Frequency interval (df)	-	6.7E-04	3.3E-04	3.3E-04	1.7E-04	
Zone A (df x Ninj)	0	1.2E-03	2.7E-03	1.1E-02	8.2E-03	**2.3E-02**
Zone B (df x Ninj)	0	8.6E-04	1.9E-03	3.7E-03	3.4E-03	**9.9E-03**
Zone C (df x Ninj)	0	2.7E-03	6.0E-03	1.1E-02	6.3E-03	**2.6E-02**

Numbers of Fatalities

For each hazard zone and each event, an estimate of the numbers of fatalities (Nf) can be made using the formula:

$$Nf = Ninj \times 2 \times HR/100$$

The results are summarised in Table AQ.38. This shows that for the 750 year event, no fatalities would be expected, whilst for the 2,000 year event around 7 fatalities would be expected.

Table AQ.38: Number of Fatalities (Nf) by Hazard Zone and by Return Period

Hazard Zone	No. at Risk (Nz)	Return Period (years)			
		750	**1,000**	**1,500**	**2,000**
A	590	0.01	0.13	2.14	4.77
B	419	0.00	0.09	0.34	1.17
C	1299	0.01	0.29	1.04	1.29
All	**2308**	**0.0**	**0.5**	**3.5**	**7.2**

Numbers of Fatalities/Year

In the same way as for injuries, the average rate of fatalities is based on both the numbers of fatalities per event (i.e. as above) and the frequency of the events. Numerically, the numbers of fatalities per year is:

$$Nf/\text{per year} = \sum (df \times Nf)$$

The associated calculations are presented in Table AQ.39. As before, it was assumed that no overflow of the defences occurred in a 1 in 500 year event.

Table AQ.39: Number of Fatalities/Year by Hazard Zone

Return Period (years)	**500**	**750**	**1,000**	**1,500**	**2,000**	**All events**
Frequency (f) (per year)	2.0E-03	1.3E-03	1.0E-03	6.7E-04	5.0E-04	
Frequency interval (df)	-	6.7E-04	3.3E-04	3.3E-04	1.7E-04	
Zone A (df x Nf)	0	4.3E-06	4.4E-05	7.1E-04	8.0E-04	**1.6E-03**
Zone B (df x Nf)	0	3.1E-06	3.1E-05	1.1E-04	2.0E-04	**3.4E-04**
Zone C (df x Nf)	0	9.5E-06	9.6E-05	3.5E-04	2.1E-04	**6.7E-04**

AQ.3.7 Measures of Risk & Acceptability

Introduction

For mapping purposes, consideration is given to two measures of risk:

- societal risk - where this is represented by the average numbers of injuries per year per square kilometre; and
- individual risk - where this is represented by the average level of risk amongst those at risk.

These measures enable some conclusions to be drawn to the acceptability of the risk and the implications for land-use planning.

Societal Risk

The measure of societal risk = 100 x Ninj/year / Zone Area (ha) = Ninj/year/km^2

The associated calculations are summarised in Table AQ.40.

Table AQ.40: Tripcock Point Societal Risk Calculations

Zone	Ninj/year	Area (ha)	Ninj/yr/ha	Ninj/yr/km^2
A	2.3E-02	9.5	2.4E-03	**0.24**
B	9.9E-03	6.5	1.5E-03	**0.15**
C	2.6E-02	18.0	1.5E-03	**0.15**

Source: Ninj/year from Table AQ./ and areas from SAQ.3.1

Individual Risk

The average individual risk (by zone) = Nf/year / Number of people at risk (Nz)

The associated calculations are summarised in Table AQ.41.

Table AQ.41: Tripcock Point Individual Risk Calculations

Zone	Nf/year	Nz	Individual Risk
A	1.6E-03	590	2.6E-06
B	3.4E-04	419	8.1E-07
C	6.7E-04	1299	5.1E-07

Source: Nf/year from Table AQ./ and Nz from Table AQ./

Acceptability of Individual Risk

The level of individual risk (IR) within each of the three zones in Tripcock Point is below the suggested risk criterion of 1 chance in 100,000 (1.0E-05) per year of being killed in a flood event. As such the level of risk is tolerable.

Application of Societal Risk Criterion

The proposed societal risk criterion is that: *the number at risk x level of individual risk < 1 x 10^{-3} per year*. As such, the maximum number at risk should be less than 1.0E-03/individual risk. The results of applying this criterion are shown in Table AQ.42.

Table AQ.42: Determination of Maximum Numbers of People

Parameter	**Zone A**	**Zone B**	**Zone C**
Level of individual risk (100% occupancy)	2.6E-06	8.1E-07	5.1E-07
Maximum number of people permitted	379	1227	1944
Maximum number of houses permitted	151	491	778

Resultant Planning Advice (based on Risk Criteria)

Application of the risk criteria results in the advice summarised in Table AQ.43.

Table AQ.43: Planning Advice based on Risk Criteria

Risk Criterion	**Area A**	**Area B**	**Area C**
Individual Risk	Residential development permitted Industrial/commercial development permitted		
Societal Risk	Maximum of 379 people (151 houses)	Maximum of 1227 people (491 houses)	Maximum of 1944 people (778 houses)
Resultant Planning Advice	Since the current proposals indicate 590, 419 and 1299 people in ground floor accommodation/premises in Zones A, B and C respectively, there is some ground for concern in Zone A (as the proposed population exceeds that determined from the suggested societal risk criterion)		

AQ.3.8 References

Scott Wilson (2004): **Tripcock Point, Thamesmead Development - Flood Risk Assessment**, report prepared for Tilfen Land and dated October 2004.

Tilfen Land (2003): **Tripcock Point Planning Statement**, Rev A dated November 2003 and associated information with particular reference to Drawing TFN 001/102 Rev A (*Residential Density Plan*). These and related documents are available from www.tilfenland.co.uk.

AQ.4. Summary of Results

The overall results are summarised in Table AQ.44.

Table AQ.44: Summary of Results

Area	Zone	Nz	Ninj/yr/km^2	Individual Risk[1]
North Cliffe	A	201	4.8	3.5E-05
	B	20	2.6	1.8E-05
	C	13	1.4	1.0E-05
South Cliffe	A	480	4.8	1.3E-05
	B	85	2.2	4.9E-06
	C	56	1.2	2.4E-06
Hull	A	689	17	5.2E-04
	B	1245	28	1.6E-04
Tripcock Point	A	590	0.24	2.6E-06
	B	419	0.15	8.1E-07
	C	1299	0.15	5.1E-07

Note: Individual Risk is the average chance of becoming a fatality per year.

By inspection of Table AQ.44, it can be seen that there is broad ranking of areas by risk from Tripcock Point (the lowest risk) through Cliffe to Hull (the highest risk). These results suggest that the following basis could be used to map risk on both an individual and societal basis using the criteria shown in Table AQ.45.

Table AQ.45: Suggested Mapping Criteria

Level of Risk	Societal Risk (as Ninj/yr/km2)	Individual Risk (as Nf/yr/Nz)
Significant	>3	>1.0E-05
Medium	0.3 - 3	1.0E-6 - 1.0E-05
Low	<0.3	<1.0E-6

If these criteria are applied, the summary of results would appear as shown in Table AQ.46.

Table AQ.46: Levels of Risk within Case Study Areas

Area	Zone(s)	Level of Societal Risk	Level of Individual Risk
North Cliffe	A	Significant	Significant
	B	Medium	Significant
	C	Medium	Medium
South Cliffe	A	Significant	Significant
	B & C	Medium	Medium
Hull	A & B	Significant	Significant
Tripcock Point	A	Low	Medium
	B & C	Low	Low

Appendix 3 Example Calculation Sheets

Riskville example

14th February 2005

Prob (Event 1) **5.0%**

Distance from river/ coast (m)	**N(Z)**	**Typical depth, d (m)**	**Typical velocity, v (m/sec)**	**Debris factor (DF)**	**Hazard rating = d(v+0.5) + DF**
0-50	25	1	1	1	2.50
50-100	50	0.25	1	1	1.38
100-250	300	0	0	0	0
250-500	1000	0	0	0	0
500-1000	2500	0	0	0	0
	3875				

Distance from river/coast (m)	**Flood warning**	**Speed of onset**	**Nature of area**	**Sum = area vulnerability**
0-50	2.15	3	2	7.15
50-100	2.15	2	1	5.15
100-250	2.15	2	3	7.15
250-500	2.15	1	2	5.15
500-1000	2.15	1	2	5.15

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	2.5	7.15	18%	4
50-100	50	1.375	5.15	7%	4
100-250	300	0	7.15	0%	0
250-500	1000	0	5.15	0%	0
500-1000	2500	0	5.15	0%	0
Sum	3875				8

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

Distance from river/coast (m)	**N(Z)**	**Factor 1 (% very old)**	**Factor 2 (% Disabled or infirm)**	**Y**
0-50	25	15%	10%	25%
50-100	50	10%	14%	24%
100-250	300	12%	10%	22%
250-500	1000	10%	15%	25%
500-1000	2500	15%	20%	35%
Sum	3875			

Distance from river /coast (m)	**N(ZE) Table 6.3**	**Y = 1 + 2 (as %)**	**No. of injuries = 2 * Y * N(ZE)**	**Fatality rate = 2 x HR**	**No. of deaths**
0-50	4	25%	2	5%	0
50-100	4	24%	2	3%	0
100-250	0	22%	0	0%	0
250-500	0	25%	0	0%	0
500-1000	0	35%	0	0%	0
All	8		4		0

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