Risks to people: developing new approaches for flood hazard and vulnerability mapping

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Proceedings of the 40th Defra Flood and Coastal Management Conference (2005)

Abstract

Flooding from rivers, estuaries and the sea poses a risk to people as well as causing significant economic impacts. 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). There were a number of fatalities associated with the Easter 1998 and Autumn 2000 floods in England and Wales (Kelman, 2003). 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 and surrounding areas.

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 Corporate Strategy, 2002-07). Over the last 50 years a wide ranges of flood risk management measures have reduced the risks to people in the UK. Nevertheless, 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. This paper describes a method for assessing and mapping risks to people that was developed within Defra/EA research project FD2321 “Risks to People Phase 2.” It introduces the concepts of flood hazard, area vulnerability and people vulnerability, provides an example of risks to people calculations for Carlisle and presents research recommendations for flood hazard and vulnerability mapping.

Introduction

Flooding from rivers, estuaries and the sea poses a risk to people as well as causing significant economic impacts. The recent Indian Ocean Tsunami in 2004 caused over 200,000 deaths, with over 100,000 people still missing in February 2005, demonstrating the vulnerability of coastal communities. In 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 number of fatalities associated with the Easter 1998 and Autumn 2000 floods (Kelman, 2003). 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 and surrounding areas.

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)

In addition the new Government flood risk management strategy aims to "manage the

adverse human and economic consequences of flooding and coastal erosion while achieving environmental and social benefits in line with wider Government objectives". (Defra, 2004)

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.

The overall objective of the Defra/Environment Agency Risks to People project was to develop a methodology for assessing and mapping the risk of death or serious harm to people caused by flooding (Figure 1). The project considered death or serious harm to people that occurs as a direct result of a flood either during or up to one week after the event. The method was tested and shown to produce sensible results on several case studies. This paper introduces the concepts of 'flood hazard', 'area vulnerability' and 'people vulnerability'; describes a case study of flooding in Carlisle in 2005 and presents research recommendations for flood hazard and vulnerability mapping.

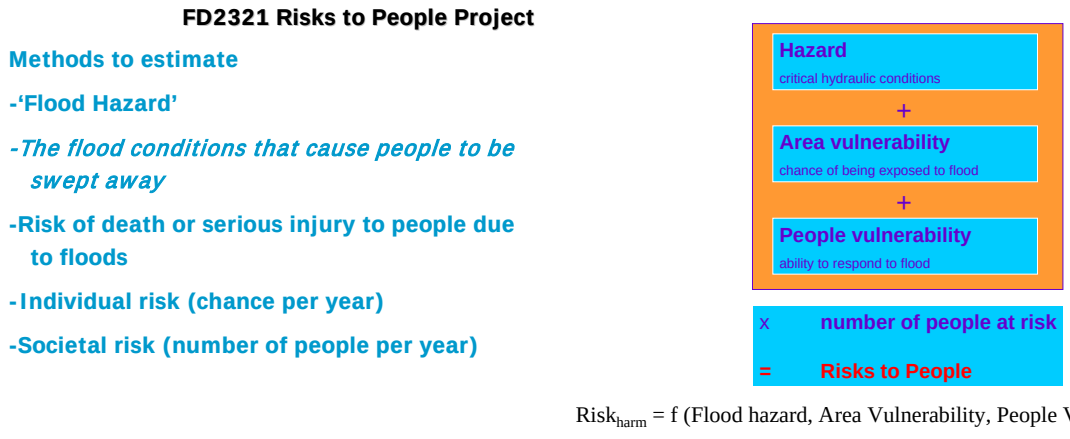


Figure 1 Overview of the Risks to People project

Risks to People concepts

The mapping methodology is a form of Multi-Criteria Assessment based on estimating key variables and scoring three concepts:- 'Flood Hazard', 'Area Vulnerability' and 'People Vulnerability.' Scores are combined individual zones of the floodplain in order to estimate the annual average individual or societal risk of serious harm or fatalities due to flooding.

- **Flood risk.** Flood risk is defined as probability multiplied by consequences. Considering the risks to people method, probability is associated with the return period of flood events. This may be a combined probability when the flood event is due to a combination of high water levels and the failure of a flood defence system. The consequences included are serious harm or fatality during or within the week following a flood event.
- **Flood Hazard** describes the flood conditions that harm people during a flood. Flood hazard maps are based on flood depths, velocities and the presence of debris for specific flood return periods, with the results classified into hazard classes. Sets of Flood Hazard maps are a component parts and by-products of the Risks to People mapping methodology. (HR Wallingford, 2005a,TR1, Section 7).
- **Area Vulnerability** describes the characteristics of an area of the floodplain that affect the chance of being exposed to the flood hazard. People are more vulnerable in areas of low rise, single-storey buildings, camp-sites and open floodplain areas than in areas of two-storey or high-rise buildings that can provide "safe refuge" above the maximum flood level.
- **People Vulnerability** describes the characteristics of the people affected by flooding and their ability to respond to ensure their own safety and that of their dependants during a flood.
- A **Flood Vulnerability map** provides information based on the concepts of Area and People Vulnerability. This map is a by-product of the Risks to People method that may be useful for other applications. Areas are mapped, typically within the Environment Agency's Extreme Flood Outline (0.1% flood) according to area and population characteristics. Flood vulnerability can be classified into Low, Medium and High classes.
- **Risks to People** combines information on the three concepts and considers a number of flood events to provide estimates of annual average individual or societal risk. A **Risks to People map** 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**.
- **Average annual individual risk** is the probability of an individual being harmed or killed due to flooding. It is calculated as the number of injuries\deaths divided by the population for each zone.
- **Average annual societal risk** is the probability of people being harmed or killed due to flooding. For mapping purposes it is calculated as the number of injuries\deaths divided by the area.
- **Acceptable risk.** The risks to people method produces average annual risk estimates. In order to use the results to inform decision making, policy makers must define a level of acceptable risk, or alternative criteria, to evaluate risks to people.

An overview of the mapping approach

The risks to people method estimates the number of injuries and fatalities for a given flood based on the values or scores for flood hazard, area vulnerability and people vulnerability:

Ninj = f (Nz, Hazard Rating, Area Vulnerability, 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 using the formula:

Nf = Ninj * 2 * Hazard Rating/100

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. The following sections provide an overview of calculations required. A full description is provided in the project Technical Reports and Guidance Documents (HR Wallingford, 2005b, 2005c).

Flood Hazard

A small number of flume and field experiments over the last 15 years have tested individual's ability to stand and walk through flood water (Abt *et al.* 1989, RESCDAM, 2000; Penning-Rowsell *et al*., forthcoming). While these can't fully simulate real flood conditions they do provide important data to identify key thresholds above which people cannot stand in floodwater due to either being knocked off balance by the speed of flow and/or becoming buoyant in deeper water. The risks to people project considered these data, alongside theoretical calculations and practical considerations to evaluate alternative flood hazard formula (HR Wallingford, 2005a; 2005b). The 'hazard rating' expression chosen for mapping risks to people was:

HR = d x (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)

Flood hazard estimates are used in the risks to people methodology to estimate numbers of injuries and fatalities in individual flood zones. The following flood hazard classes, for a situation without significant debris present, provide a guide to the degree of flood hazard for people in floodwater.

Table 1 Flood hazard classes

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"

Area Vulnerability

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

- outdoors on foot
- outdoors in a vehicle
- indoors within a basement or 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
- nature of area

The flood warning score is calculated with reference to Environment Agency Key Performance Indicators for flood warning as follows:-

FW Score = 3 - (P1 x (P2 + P3))

where, P1 = % of Warning Coverage Target Met;

P2 = % of Warning Time Target Met; and

P3 = % of Effective Action Target Met.

This score is used within the 'area vulnerability' scoring system summarised below:-

Table 2 Area vulnerability

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'			

People Vulnerability

A wide range of factors that contribute to people vulnerability were considered in the research and are described in draft guidance material developed by the project (HR Wallingford, 2005c). The two key factors that are used in the mapping methodology are:-

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

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

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

The research highlighted a range of additional factors that influence vulnerability. These were not included in the method but provide a useful check-list for future research or guidance:-

Additional vulnerability factors

- The Financially Deprived
- Single Parents and Children
- Language and Ethnicity
- Transient and Recent Immigrants
- Leisure-related vulnerability
- The Roofless Homeless

Estimating risks to people: A case study of Carlisle

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

- 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 x (v + 0.5) + DF. Substituting the values derived above is shown in Table 3.

Table 3 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). The Key Performance Indicator data were not available so a score within this range was applied. 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 that 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 4.

Table 4 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:

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

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

The values for Nz (the number of people at risk) were derived by zone as shown in Table 5 using an assumed value of four persons per non-residential premises.

Table 5 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/	400	2.1	12	888
E	Botcherby	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.

Table 6 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[1] 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) that is highlighted by the method as the area with the highest risk.

Considering multiple events

The Carlisle case study shows how the method works for a single event but the overall method involves estimating annual average risks. The project Technical Report (HR Wallingford, 2005b) provided a hypothetical case study of “Riskville”, a village of 3785 people at risk from fluvial flooding but with no formal flood defences, to demonstrate the full methodology. Table 7 shows how the results of several events would be combined for zones at increasing distance from the river and how the results, in this case for average annual individual risk of injury, could be compared to an acceptable o tolerable risk threshold.

[1] 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)

Table 7 Estimation of annual average risk for "Riskville."

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)					

Flood hazard mapping guidance

Flood hazard maps, typically for 5 return periods, are a component part and useful by-product of the Risks to People method. The project Technical Reports provide guidance on flood hazard mapping (HR Wallingford, 2005c) so only the key steps are summarised below:

1. Define the problem. Establish clear aims & objectives for the mapping work, define the detail required, modelling approaches etc….
2. Develop an understanding of flood hazard. For example from descriptions of historical floods or existing 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 or defence length
   - Existing flood outlines for several return periods.
   - Flood hazard classes from an extreme flood (i.e. 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.

Risks to people mapping guidance

"Risks to people" zones can be defined by overlaying flood hazard and "nature of area" zones. Other variables required can be interpolated, aggregated or generalised to these zones using a Geographical Information System for estimating risks to people using the full method based on five flood events. The risks

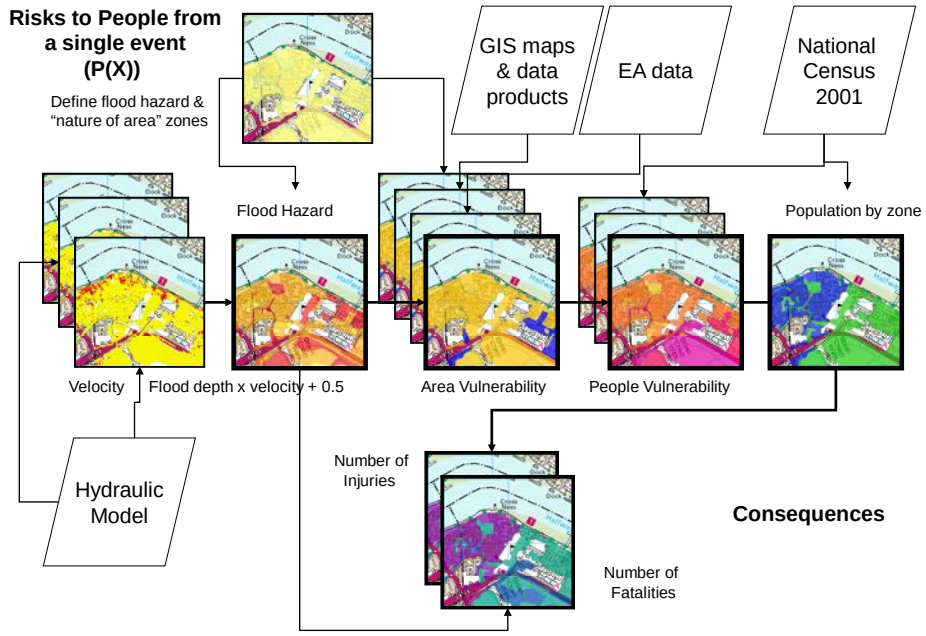
to people calculations can then be completed for each area and several return periods to estimate average annual risk.

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

The results of the risks to people research project have been taken forward in a number of other Defra and Environment Agency studies, for example FD2320 on flood risks for new development, the Thames Estuary 2100 project and an Environment Agency Flood Hazard Scoping Report. The full method or its component parts of a range of potential applications including:

- Flood mapping
- Flood defence regulation and development control
- Land use planning
- Flood Plans for reservoirs
- Project appraisal
- Flood warning
- Emergency planning and response
- Flood awareness
- Proving information for ongoing research projects such as Flood SITE

The overall mapping methodology is summarised in Figure 2. The generic mapping methodology and potential areas of application were discussed in the project Technical Reports (HR Wallingford, 2005b, 2005c).



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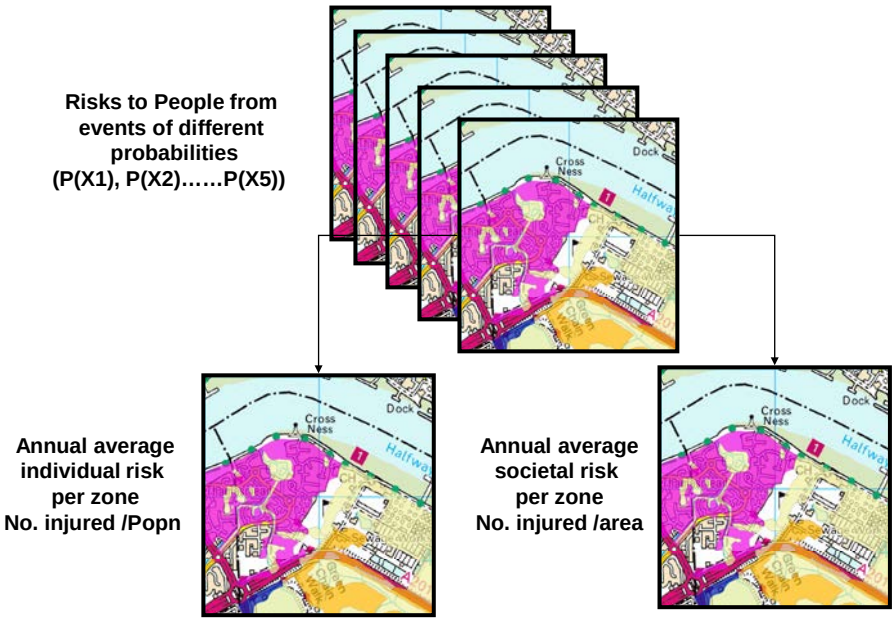

(ii)

Figure 2 Illustration of the mapping methodology for (i) a single flood event and (ii) combining results from multiple events

Conclusions

The research project has developed a practical methodology for assessing and mapping risks to people for a range of potential applications. With regard to flood hazard and vulnerability mapping the main conclusions are summarised below.

Flood hazard mapping

1. Flume tests have shown that people can lose stability in floodwater at low depths (25 cm) and fast velocities (>2 m/s).
2. Flood hazard formulae can be used to estimate the when people of different heights and weights will lose stability. Thresholds can be derived that indicate whether flood hazard is “dangerous” for “some”, “most” or “all” people.
3. Flood hazard mapping must start with a good conceptual understand of how depths and velocities vary across floodplains for a range of events. Flood hazard zones can be defined based on information from historical floods, floodplain mapping studies that produce outlines for different events or simply distance from the source of flooding.
4. There is considerable uncertainty regarding the scoring of the debris factor and also in the quality of velocity data from hydraulic models. These uncertainties need to be recognised and should be the subject of further research.
5. Despite the uncertainties flood hazard mapping is clearly a step in the right direction towards more sustainable flood risk management that will enable risks to people to be considered alongside economic and environmental risks.

Vulnerability mapping

1. Vulnerability maps that consider the concepts of area and people vulnerability can help to target and develop appropriate flood risk management measures. Different approaches to mapping will be appropriate at different scales, for example for Catchment Flood Management Plans, understanding vulnerability at a broad scale would be appropriate but much more detailed mapping is required for flood warning and emergency planning applications.

General conclusions

1. There are a number of issues that need to be addressed before the approaches are fully implemented. For example how to assess the combined probabilities of defence failure and flood hazards; the appropriate choice of mapping scales and levels of risk assessment and the integration of risks to people with economic impacts. Many of these issues are addressed in the other projects such as Risk Assessment for Strategic Planning (RASP), National Flood Risks Assessment project and FloodSITE. The integration of these approaches will provide improved national, regional and local flood risk mapping.

Acknowledgements

Defra and the Environment Agency funded this research (project FD2321). The authors acknowledge the efforts of the risks to people project team members from HR Wallingford, Risk & Policy Analysts and FHRC and the guidance and comments from the Project Board.

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