Integrated Flood Risk Analysis
and Management Methodologies

FLOODsite

Building models to estimate loss of life for flood events

EXECUTIVE SUMMARY

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Executive Summary for Building models to estimate loss of life for flood events (Task 10)

1. Scope of the research

1.1 Introduction and aims of Task 10 and this research

The research described in this Executive Summary forms part of Task 10 which focused on developing innovative methods to understand, model and evaluate flood socio-economic and ecological damages. The research comprised four quite distinct activities which are described within separate Executive Summaries. The four components included in this Task are:

1. Building a model to estimate Risk to Life for European flood events (project document T10-07-10)
2. Modelling the damage-reducing effects of flood warnings (project document T10-07-12)
3. Toxic Stress: the development and use of the OMEGA modelling framework in a case study (project document T10-07-14)
4. GIS-based Multicriteria Analysis as Decision Support in Flood Risk Management (project document T10-07-06).

Each of these Activities comprises a separate, and substantial, research project in its own right encompassing the use of different disciplines and approaches. These reports should be referred to for full accounts of the individual research projects, including full literature reviews, research methodologies, results and discussions. The Deliverable report for the Task comprises abridged versions of each of these reports.

The research focuses on methodologies to determine damages, losses and benefits to *receptors*, that is: people, buildings and the environment. The overall combined results from the research should lead to a better understanding and quantification of flood impacts and therefore the provision of evaluation methodologies, techniques and approaches to guide end-users in decisions on levels of investment, preparedness planning and emergency response strategies in future flood risk management across Europe.

The results outlined in this Executive Summary comprise the outputs from research investigating approaches to estimating the loss of life from flood events. In order to reduce the risk to life from flooding it is necessary to understand the causes of loss of life in floods in order to pinpoint where, when and how loss of life is more likely to occur and what kind of intervention and flood risk management measures may be effective in eliminating or reducing serious injuries and fatalities. The objectives of this research were therefore:

- to further develop a model, or models, to provide insight into, and estimates of, the potential loss of life in floods, based on work already undertaken in the UK and new data collected on flood events in Continental Europe;
- to map, through the use of GIS and building partly on existing work, the outputs of the risk to life model(s) providing estimates of the potential loss of life in floods.

The research took as a starting point the *Risk to People* model developed in the UK (HR Wallingford, 2003; 2005) and assessed the applicability of this model for flood events in Continental Europe, which tend to be more severe and life threatening. Data on flood events were gathered from 25 locations across six European countries as well as data from an additional case study in the UK. It also aimed to produce risk to life models that are usable at different scales. This flexibility is essential as not all European countries have detailed flood data that is readily available. Therefore a broader “threshold” model has been developed for situations where there is little detailed data available, while a more refined model can be used where more extensive local data exists. It needs to be noted that although Europe experiences many different types of flooding, this research only examines risk to life related to fluvial flooding; coastal or other types of flooding have not been included.

1.2 European Floods Directive

The research directly relates to the European Directive on the Assessment and Management of Flood Risks (EU 2007/60/EC of 23 October 2007) in a number of ways, as outlined in Table 1.1 below.

Table 1.1: Relevance of research to EU Floods Directive

Article in Directive	Research developments
Article 1: contributing innovative evaluation and modelling methodologies "aiming at reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community".	Development of a new model to estimate levels of *risk to human life and injuries* from flood events.
Article 4 (2b): by providing "a description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity, and for which the likelihood of similar future events is still relevant, including their flood extent and conveyance routes and an assessment of the adverse impacts they have entailed".	Detailed case studies and description of past flood events. Analyses of factors influencing risk to human life and health from different types of flood events and in different locations and contexts.
Article 4 (2d): by providing "an assessment of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity".	Development of a new model to estimate levels of *risk to human life and injuries* from flood events.
Article 6 (2, 4, 5): by "the preparation of flood risk maps for at-risk areas showing such elements as: flood extent, depths and flow velocity, potential adverse consequences expressed in terms of indicative number of inhabitants potentially affected, type of economic activity, information on floods with a high content of transported sediments and other significant sources of pollution" and other factors.	Methodology for mapping Risk to Life along with example maps from case studies.

2. Principal results

The aim of this research was to better understand the process of loss of life in flood events. Along with the increase in the frequency of flood events in recent years there has been a rise in the numbers of deaths reported and attributed to flooding. Yet, to date, we know very little about the likely loss of life in floods, and the various causes. We do not yet have appropriate techniques that predict the incidence of loss of life in floods, or the potential for flood mitigation measures to reduce this loss. Therefore, in order to reduce the risk to life it is necessary to understand the causes of loss of life in floods to pinpoint where, when and how loss of life is more likely to occur and what kind of intervention may be effective. In particular, with reference to the Source-Pathway-Receptor risk approach this research focused on methodologies to determine damages and losses to people, i.e. human *receptors*.

2.1 Methods to calculate flood risks to people

Several methods have been developed as a means to calculate the potential risk to life from flood events. The number of fatalities caused in a flood depends on a large number of characteristics, however, most of the models limit themselves by only taking into account some of these characteristics when modelling loss of life (Jonkman *et al.*, 2002). Moreover, many of the existing risk to life models are designed to predict fatalities for either large-scale floods caused by flood defence failure in low-lying areas (e.g. Jonkman, 2003, 2007) or dam or dike break scenarios (e.g. Waarts, 1992, Graham, 1999). As flood events in many other parts of Europe are quite different from these situations these models may not be applicable.

One project in the UK that developed a different model to predict loss of life was the *Flood Risks to People* Project (HR Wallingford, 2003; 2005a). The *Flood Risk to People* method is different in that fatalities for a particular event are calculated as a function of injuries, which in turn are estimated according to the flood, area, and population characteristics, rather than applying a uniform mortality fraction to the exposed population as in the other studies. Three broad sets of characteristics were used to determine the number of fatalities and serious injuries from a flood event:

- Flood characteristics (depth, velocity, etc.)
- Location characteristics (inside/outside, nature of housing)
- Population characteristics (age, health, etc.) (HR Wallingford, 2003).

Based on these characteristics, a formula was developed to calculate the number of injuries produced by a single flood event.

2.2 Calibration of UK model with European data

As the *Risk to People* model has been useful in the assessment of risk from flooding in the UK, this model was taken to form the basis for modelling of risk to life within Task 10 and was tested for its applicability within the wider European context by being calibrated using data from various European flood events. Following the results of this calibration with European flood event data, the aim was to refine the model, if necessary, to apply to flooding in the rest of Europe. Data were gathered for flood events between 1997 and 2005 at 25 locations across six European countries, providing 43 different data zones which recorded 82 deaths.

The *Risk to People* model results for UK case studies are reasonable estimates, however when calibrated with the wider European data, in the majority of cases it over-predicted the number of fatalities and injuries, in many cases severely so. The model was found to contain two structural weaknesses: a Hazard Rating (HR) of greater than 50 yields the result that more fatalities are predicted than injuries; when HR and People Vulnerability (PV) values are high the model becomes unstable and tends to predict more injured people than are in the hazard zone. This is partly because the high Hazard Rating often associated with floods in Continental Europe and a logical flaw in the model that simply did not apply at the comparatively low HR values obtained in the UK.

Analyses were undertaken to compare and contrast the ways in which people died in UK events with the factors surrounding deaths in the wider European case studies. This was in order to determine whether there are any differences which might be leading to the over-prediction of deaths observed. Results from the European flood events indicate four broad sets of flood characteristics that can be identified which are seen to influence the number of fatalities or injuries:

- Area characteristics (exposure, density of population, type and structure of buildings – affecting building collapse, flood warnings etc.)
- Flood characteristics (depth, velocity, debris, speed of onset, time of day/year etc.)
- Population characteristics (age, prior health, disability, language constraints, presence of tourists/visitors, behaviour, risk awareness etc)
- Institutional response (evacuation, rescue etc.)

The UK model further does not take into account flood damage to buildings and the risk to people associated with building collapse (the main cause of fatalities in a number of European cases), nor does it consider a 'vehicles factor' and the fact that a high number of fatalities occur in motor vehicles. Insufficient account is also taken of institutional arrangements such as evacuation and rescue operations in the Area Vulnerability (AV) component of the model. The model is also hugely sensitive to PV which is arguably of less importance in the wider European context than it is in the UK due to the more severe Hazard Ratings. A UK case study of the 2004 Boscastle flood (discussed in detail in document T10-07-10) was used to illustrate how the context of modern flood warning practices, incident management and search and rescue scenarios can be significant in reducing loss of life and how a series of circumstances and the efforts of rescuers can greatly alter the chances of experiencing fatalities from flood events. Loss of life is thus caused by a combination of the above characteristics and varying combinations provide different potential scenarios and risk to life.

Although redesigning the model would ideally require good quality data from many more flood events than were available for this research, some simple alterations were made to the existing model in an attempt to improve its predictive capability. Several recommendations for refinement of the *Risk to People* methodology were made (guided by sensitivity and statistical analyses) to make it more applicable within a wider European context:

- People vulnerability should be given less prominence
- Place more prominence on the effect of flood warning
- Place more prominence on type of buildings
- Include a population density factor
- Place more prominence on the debris factor

2.3 Developing a new European Risk to Life model

At the highest level, the theory explored within the original *Risk to People* model is still applicable to the situation in Europe (Figure 2.1).

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

Where E is the nature/extent of effects (on those exposed), F is the flood characteristics (depth, velocity), L is the location characteristics (inside/outside buildings, nature of housing etc) and P is the population characteristics (age, health) (HR Wallingford, 2003, p15).

Figure 2.1: Expression characterising the effects on people exposed to the flooding risk

Adding the numbers of people who are exposed to the hazard the *Risk to People* approach is illustrated in the following diagram (Figure 2.2).

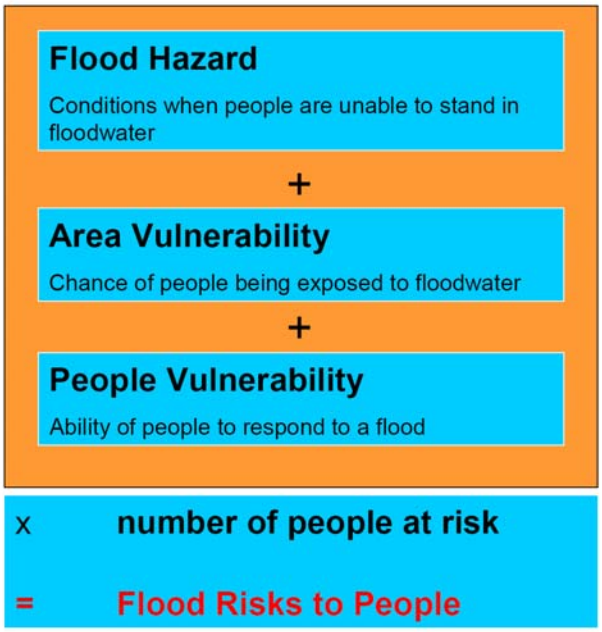

Figure 2.2: Method for calculating flood risks to people.

Source: HR Wallingford (2005b, p2)

However, according to the analyses of the situation within other parts of Europe outlined above, this does not really fully explain the situation leading to risk to life from flooding. Although Figure 2.3 does address the broad issues involved in assessing the risk to life from flooding, when considering the situation in Europe it is possible to propose a more specific conceptual model.

$$\text{Risk to Life in Europe} = f(F, E_x, P_v, -M)$$

Where:

F is the flood hazard characteristics (e.g. depth, velocity),
E_x is the exposure to the hazard (related to the nature of the area, whether people can avoid direct contact with the flood waters without being threatened by building collapse),
P_v is people vulnerability (the importance of this variable will depend upon the severity; for instance in some circumstances, such as very severe floods, this variable is redundant)
M are the mitigating actions (is there sufficient warning to enable people to evacuate the area entirely or seek appropriate shelter from the flood waters).

Figure 2.3: Proposed conceptual model for assessing risk to life

Flood hazard factors

For the new model Figure 2.4 calculates the depth-velocity function (i.e. the flood depth multiplied by the velocity of the flood) for each variable and identifies potential new thresholds based on a depth-velocity product. The colours in this diagram relate to those depth-velocity products that HR Wallingford (2005a) recognised as being ‘dangerous to some people’ (yellow), ‘dangerous to most people’ (orange) and ‘dangerous to all people’ (red).

		Depth									
		0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
Depth x Velocity	0.25	0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.50	0.5625	0.625
	0.5	0.125	0.25	0.375	0.5	0.625	0.75	0.875	1.00	1.125	1.25
	1	0.25	0.5	0.75	1	1.25	1.5	1.75	2.00	2.25	2.5
Velocity	1.5	0.375	0.75	1.125	1.5	1.875	2.25	2.625	3.00	3.375	3.75
	2	0.5	1	1.5	2	2.5	3	3.5	4.00	4.5	5
	2.5	0.625	1.25	1.875	2.5	3.125	3.75	4.375	5.00	5.625	6.25
	3	0.75	1.5	2.25	3	3.75	4.5	5.25	6.00	6.75	7.5
	3.5	0.875	1.75	2.625	3.5	4.375	5.25	6.125	7.00	7.875	8.75
	4	1	2	3	4	5	6	7	8.00	9	10
	4.5	1.125	2.25	3.375	4.5	5.625	6.75	7.875	9.00	10.125	11.25
	5	1.25	2.5	3.75	5	6.25	7.5	8.75	10.00	11.25	12.5

Figure 2.4: Recalculation from the HR Wallingford (2005a) of the 'danger' thresholds for a range of different depths and velocities.

Adapted from HR Wallingford (2005a, p9).

It is acknowledged that an individual's ability to remain stable in flood waters is not only a function of the depth and velocity of the water, and their height and weight, but may also be linked to other variables such as their physical condition, or other circumstances such as lighting, underfoot conditions, cold water, presence of debris in the water or if they are carrying a load or assisting other people. Different experiments and assessments of this variable have provided different estimates of these figures. Therefore based on the literature discussed above, a range of variables are provided in Table 2.1, presenting a low, mid, high and extreme estimate to all of the thresholds. However, if nothing is known about these additional variables it is recommended that without additional research the mid-range value should be used.

Table 2.1: Flood hazard thresholds as a function of depth and velocity

Depth x velocity (m^2/s)			Hazard from flooding	Description
Low range	**Mid-range**	**High Range**		
<0.1	<0.25	<0.50	Low	**Caution** *"Flood zone with shallow flood water or deep standing water"*
0.10 to 0.30	0.25 to 0.50	0.25 to 0.70	Moderate	**Dangerous for some (i.e. children and elderly)** *"Danger: Flood zone with deep or fast flowing water"*
0.40 to 0.70	0.5 to 1.10	0.90 to 1.25	High	**Dangerous for most people** *"Danger: Flood zone with deep fast flowing water"*
0.9 to 1.25	1.10 to 3.00	>3.00	Extreme	**Dangerous for all** *"Extreme danger: Flood zone with deep fast flowing water"*

Source: Adapted from HR Wallingford (2005a, p8).

It was also necessary to add an additional depth-velocity threshold to the model to reflect at which point the majority of buildings will be vulnerable from collapse; thereby making people directly vulnerable not only to the flood waters but to the effects of building collapse itself. The additional threshold of > 7m²/s where all buildings that are in direct contact with the flood waters are vulnerable (assuming that velocity ≥ 2m/s) is added in Table 2.2

Table 2.2: Flood hazard thresholds as a function of depth and velocity (additional threshold)

Depth x velocity (m²/s)			Hazard from flooding	Description
Low range	**Mid-range**	**High Range**		
<0.1	<0.25	<0.50	Low	**Caution** *"Flood zone with shallow flood water or deep standing water"*
0.10 to 0.30	0.25 to 0.50	0.25 to 0.70	Moderate	**Dangerous for some (i.e. children and elderly)** *"Danger: Flood zone with deep or fast flowing water"*
0.40 to 0.70	0.5 to 0.11	0.90 to 1.25	High	**Dangerous for most people** *"Danger: Flood zone with deep fast flowing water"*
0.9 to 1.25	1.1 to 7.00	>7.00	Extreme	**Dangerous for all** *"Extreme danger: Flood zone with deep fast flowing water where properties will be prone to structural damage; poorly-constructed and wooden buildings may collapse."*
>7.00	>7.00	>7.00	Extreme	**Dangerous for all** *"Extreme danger: Flood zone with deep fast flowing water where all properties are vulnerable to collapse or serious structural damage"*

Source: Adapted from HR Wallingford (2005a, p8).

2.4 Area vulnerability factors

Table 2.3 integrates all of the different components of the vulnerability of the area and identifies those areas that are best able to reduce the chances of an individual's exposure to the floodwaters.

Similar to the approach adopted in the *Risk to People* methodology, three categories are proposed to indicate the different vulnerabilities for locations affected by flooding. These categories are based on four main factors: type of land use (i.e. whether there are proper buildings where shelter can be sought); number of floors of a property, indicating whether people are able to escape from flood waters; structural integrity of buildings, their building material and the integrity of construction; and the presence of particularly vulnerable groups or activities (e.g. schools, residential care homes).

Table 2.3: Categories indicating an area's vulnerability to flood waters

1. Low Vulnerability	**2. Medium vulnerability**	**3. High vulnerability**
These areas will have multi-storey buildings that would provide safer places for people to escape to. These areas will also have well-constructed properties made out of solid materials such as masonry concrete and brick	This category is a typical residential area with mixed land use (e.g. residential and industrial mixes) and mixed types of buildings (i.e. areas with single and multi-storey properties)	This category will include areas which provide little protection to individuals from flood waters. The type of land use within this zone would include mobile homes, campsites. It also includes areas of poorly-constructed properties which would be more vulnerable to structural damage or collapse and single storey dwellings which would only offer limited protection in deep waters.

2.5 Threshold levels of risk to life and dominating factors

From the information above it is possible to construct a threshold model highlighting the consequences of flooding at different depths and velocities using the depth-velocity product. Figure 2.5 combines the thresholds for people directly exposed to the flood waters and the information about whether particular areas are vulnerable; it illustrates these thresholds and identifies the risks associated with flood waters at each of the different levels. The model provides four different risk levels each also illustrated by a different colour; Extreme risk (red), High risk (orange), Medium risk (yellow) and Low risk (green).

It is also possible with this model of Risk to Life to provide some indication of the dominating factors leading to injuries and fatalities from flooding of difference levels. This is illustrated in Table 2.4 and Figure 2.5, which comprise the first part of the new Risk to Life model. However, due to the complexity of the factors leading to death, and particularly in relation to those areas in the most vulnerable zones where physically vulnerable properties are found due to poor construction or unsuitable materials, this can only be a broad assessment. The second half of the model (discussed in Section 2.6) adds a mitigation factor to the model and thereby takes account of those actions that can be taken to reduce the risk of injuries and fatalities from flooding.

Table 2.4: Main factors leading to fatalities from flooding

Depth-velocity thresholds (m^2/S)	Nature of area categories	Main factor leading to fatalities	Description
<0.25	All	Low risk	There is low risk to people from the flood waters.
0.25 – 0.50	All	People Vulnerability dominated – some Behaviour-related	The fatalities are likely to be concentrated amongst the vulnerable people e.g. children either playing in or near flood waters, or elderly people (often trapped in their properties)
0.50 – 1.10	Low and medium vulnerability	Behaviour dominated	In most circumstances people will be able to find shelter away from the floods, however, deaths and injuries may still occur if people undertake risky activities such as driving through the floodwaters or taking unnecessary risks in the waters
0.75-1.75	High vulnerability	Hazard dominated	In these situations, fatalities are likely to occur from direct contact with the flood waters
1.75-7.00	Low and medium vulnerability		
1.75-7.00	High vulnerability	Hazard and building collapse dominated	Fatalities will occur if people are in direct contact with the flood waters or if caught in buildings that are structurally compromised by the flood waters.
>7.00	All		

DEPTH x VELOCITY MID-RANGE	OUTDOOR HAZARD	NATURE OF THE AREA	STRUCTURAL DAMAGE	RISK TO LIFE FROM FLOODING	FATALITY FACTOR
$>7m^2s^{-1}$	Extreme Dangerous for all	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Total collapse may occur. Structural damages probable in particular for properties with poor quality building fabric	Risk to life in this scenario is extreme as not only are those in the open very vulnerable to the effects of the flood waters but those who have also sought shelter are also very vulnerable due to the fact that building collapse is a real possibility	Hazard and building collapse dominated
		2. Medium vulnerability (Typical residential area mixed types of properties)			
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)			
1.10 to 7 m^2s^{-1}		**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)		All those exposed to the hazard outside will be in direct danger from the floodwaters. Those living in mobile homes will be at risk from the high depths and velocities and those in single storey dwellings will be at risk from not being able to escape to upper floors. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse.	
		2. Medium vulnerability (Typical residential area mixed types of properties)	Structural damages possible	All those exposed to the hazard outside will be in direct danger from the floodwaters. Damages to structures are possible. Those in unanchored wooden frames houses are particularly vulnerable. With very deep waters there is the risk of some not being able to escape.	Hazard Dominated
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		All those exposed to the hazard outside will be in direct danger from the floodwaters. In this scenario those residing in these properties have the lowest risk although structural damages are still possible in wooden properties	
0.50 to 1.10 m^2s^{-1}	High Dangerous for most	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Structural damages and collapse possible for properties with poor quality building fabric	Those outside are vulnerable from the direct effects of the floodwaters. In addition, those in single storey dwellings will be vulnerable in deeper waters. People will also be afforded little protection in mobile homes and campsites. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse. Vehicles are also likely to stall and lose stability.	
		2. Medium vulnerability (Typical residential area mixed types of properties)	Structural damages – less likely and less severe	Anyone outside in the floodwaters will be in direct danger. It is at this point where behaviour becomes significant as structural damages are less likely; those inside should mostly be protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside when is it not necessary?	Behaviour dominated
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		Anyone outside in the floodwaters will be in direct danger from the floodwaters. It is here at this point where behaviour becomes significant as structural damages are less likely so those inside should be on the most part protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside when is it not necessary?	
0.25 to 0.50 m^2s^{-1}	Moderate Dangerous for some	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Structural damages possible for properties with poor quality building fabric	Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly); in this category the shelter may not protect them. Motor vehicles may become unstable at these depths and velocities. Those in very poorly constructed properties may also be vulnerable from structural damages.	People vulnerability dominated though some behaviour-related fatalities
		2. Medium vulnerability (Typical residential area mixed types of properties)	Unlikely	Only the most vulnerable should be in direct danger from the floodwaters (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.	
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.	
$<0.25 m^2s^{-1}$	Low Caution	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Unlikely	A very low risk to adults either out in the open or who is in a property. There may be a threat to the stability of some vehicles even with these low depth-velocity factors.	Low risk
		2. Medium vulnerability (Typical residential area mixed types of properties)			
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)			

Figure 2.5: First half of threshold model indicating the risk of life from flooding

It is also important to remember that at all levels of flood severity (i.e. those events with a higher depth-velocity component) people vulnerability will remain a factor as those in this category are potentially less able to take action on their own or evacuate from areas. Similarly, the behaviour of people during flooding is also important, particularly on the fringes of the very high hazard zones where depths and velocities will be lower but still will be dangerous. Therefore, undertaking risky or inappropriate activities at higher depth/velocity levels will still impact greatly upon an individual's risk of injury or death from flooding.

2.6 Mitigating factors

After defining the factors that contribute to the flood hazard it is important to realise that in most cases actions are taken to not only reduce the impacts of these flood hazards but also to reduce the public's exposure to the hazard. Thus, the second part of the model adds two additional categories: *no flood warning available or a short lead time* and *effective flood warning with adequate lead time.*

Table 2.5 indicates the four broad categories of mitigating factors that have been added to the model. However it is acknowledged that these categories might be able to be more refined and detailed when applying the model to a specific region or town. For instance, if an area is subject to flash flooding, broad-scale evacuation prior to the event is unlikely, as is flood warning with adequate lead time, therefore category 4 (*No flood warning or short lead time)* should be assigned. Similarly, this category would be assigned to regions that have no flood warning systems or regions where, in the case of past flooding, flood warnings have not been effective. Regions that have effective flood warning systems with good evacuation plans in place might chose to select categories 1 (*Full evacuation*) or 2 (*Partial evacuation*) depending upon past experiences.

Table 2.5: Categories of mitigating actions

Mitigating factor	Description	Outcome
1. Full evacuation following a flood warning	A flood warning and then evacuation order have been provided in sufficient time before the flooding. There are plans and resources in place to enable the majority of those in the risk zone to evacuate (or self-evacuate) from the risk zone.	Most people have been able to evacuate the area and therefore not exposed to the flooding
2. Partial evacuation following a flood warning	A flood warning and then evacuation order have been provided with sufficient time before the flooding. There are plans and resources in place to enable some of those in the risk zone to evacuate (or self-evacuate). Some of those remaining in the area at risk would have received a flood warning and will have had the opportunity to seek shelter. In some instances the partial evacuation might be targeted at vulnerable groups, such as children or the elderly. Some people may not receive the warning or advice to evacuate or may choose not to leave the area.	Some people have evacuated the area following receipt of a warning. The rest of the population remain *in situ* but have had the chance to receive a flood warning and have had the time to react.
3. Flood warning with adequate lead time with mixed responses	A percentage of the population will have received a flood warning with enough time to react and get to safety. There may however be mixed effectiveness of this warning system and/or mixed responses to the warning. This may depend on the dissemination strategy, the experience of the warning agency and/or the people and awareness of the most appropriate action to take.	Most people remain *in situ* and therefore may be exposed (or expose themselves). But the flood warning will permit people the time to react and seek shelter.
4. No flood warning or short lead time	This may be a region that has no (or an ineffective) flood warning service. It may also be a area of flash flooding, where forecasting and warning with sufficient time for an effective warning to be delivered is difficult.	The majority of the population are *in situ* when flooding occurs and are not warned or warned very close to the flood occurring.

All of these categories do not take into consideration "unofficial" or unplanned action by individuals or communities (though the model could be refined to do this if a region has good information about how the public have reacted in past floods) nor are they able to account for the effectiveness of a person's response to these factors. Therefore local experience of the flooding situation and how people react to flooding would need to be added to the model, and the categories refined, in order to improve on the assessment provided, although it is difficult to see how this could be done.

2.7 A new approach to assessing Risk to Life from flooding in Europe

Figure 2.6 combines the hazard and exposure thresholds and the mitigating factors to provide a new model from which the risk to life can be assessed at different scales. Although only a broad assessment, this approach can be applied at a range of scales (though as mentioned previously it might be developed and refined further for a local or regional context). The purpose of the model is to allow flood managers to make a general and comparative assessment of risk to life and also where to target resources before, during and after flooding. The final column provides some high-level suggestions, although these again may be made more detailed depending on the scale of application and the purpose (e.g. for planning evacuation, the locating of emergency shelters or where enhancing flood risk awareness should be targeted). One advantage of this scaled approach is that although it is still necessary to zone areas according to the hazard characteristics and vulnerability, it is not necessary to zone them homogenously for both features. Therefore, areas of differing hazard and areas of differing vulnerability can overlap and intersect and a risk level be assessed for each different combination.

RISK TO LIFE WITHOUT ANY MITIGATING ACTIONS						RISK TO LIFE WHEN MITIGATING ACTIONS ARE APPLIED		
D x V FACTOR MID-RANGE[1]	**OUTDOOR HAZARD**	**NATURE OF THE AREA (VULNERABILITY)**	**STRUCTURAL DAMAGES**	**RISK TO LIFE CATEGORIES WITHOUT MITIGATION**	**MAIN FACTOR LEADING TO FATALITIES**	**MITIGATION FACTOR[2]**	**RISK TO LIFE WITH ACTIONS**	**ACTIONS[3]**
>7m^2s^{-1}	Extreme Dangerous for all	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Total collapse may occur. Structural damages probable in particular for properties with poor quality building fabric	Risk to life in this scenario is extreme as not only are those in the open very vulnerable to the effects of the flood waters but those who have also sought shelter are also very vulnerable due to the fact that building collapse is a real possibility	**Hazard and building collapse dominated**	**No flood warning or short lead time**		The emphasis in these situations should be on search and rescue if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. If possible, a flood warning service should be developed. Where possible ensure that people do not reside in areas that suffer such severe flooding where there is no flood warning.
						Flood warning with adequate lead time and mixed response		The emphasis in these situations should be on search and rescue if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs.
		2. Medium vulnerability (Typical residential area mixed types of properties)				**Partial evacuation following a flood warning**		Focus should be on ensuring that as many people as possible are evacuated safely (i.e. with enough time not to be caught out in the flooding). Search and rescue operations can then focus on the smaller number of people who remain in the risk area. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs.
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)				**Full evacuation following a flood warning**		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area. This zone is not green because there is likely to be some risk during the evacuation period and also because of the fact that these events may not occur in isolation (i.e. people might need to move through areas of more minor flooding.)
1.1 to 7 m^2s^{-1}		**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)		All those exposed to the hazard outside will be in direct danger from the floodwaters. Those living in mobile homes will be at risk from the high depths and velocities and those in bungalows will be at risk from not being able to escape to upper floors. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse.		**No flood warning or short lead time**		The emphasis in these situations should be on search and rescue if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. If possible, a flood warning service should be developed. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Flood warning with adequate lead time and mixed response		The emphasis in these situations should be on ensuring that as many people as possible are warned and know what to do to protect themselves, following this search and rescue should be carried out if this is possible. Proactively, education should focus on flood risk awareness and preparation. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Partial evacuation following a flood warning		Focus should be on ensuring that as many people as possible are evacuated safely (i.e. with enough time not to be caught out in the flooding). Search and rescue operations can then focus on the smaller number of people who remain in the risk area. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area. This zone is not green because there is likely to be some risk during the evacuation period and also because of the fact that these events may not occur in isolation (i.e. people might need to move through areas that are flooding to a lesser degree.) Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
		2. Medium vulnerability (Typical residential area mixed types of properties)	Structural damages Possible	All those exposed to the hazard outside will be in direct danger from the floodwaters. Damages to structures are possible. Those in unanchored wooden frames houses are particularly vulnerable. With very deep waters there is the risk of some not being able to escape.	**Hazard dominated**	**No flood warning or short lead time**		The emphasis in these situations should be on search and rescue if people are exposed if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger (e.g. those on the ground floor). Efforts and resources should also be targeted at ensuring that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. If possible, a flood warning system should be developed.
						Flood warning with adequate lead time and mixed response		The emphasis in these situations should be on ensuring that as many people as possible are warned and know what to do to protect themselves and where to go for safety, following this search and rescue should be carried out if this is possible. Proactively, education should focus on flood risk awareness and preparation. Where possible ensure that vulnerable land uses are not located in areas that could suffer such severe flooding.
						Partial evacuation following a flood warning		Focus should be on ensuring that as many people as possible are evacuated safely (i.e. with enough time not to be caught out in the flooding). Search and rescue operations can then focus on the smaller number of people who remain in the risk area. Efforts and resources should also be targeted at ensuring that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. Where possible ensure that vulnerable land uses are not located in areas that could suffer such severe flooding.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area.
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		All those exposed to the hazard outside will be in direct danger from the floodwaters. In this scenario those residing in these properties have the lowest risk although structural damages are still possible in wooden properties		**No flood warning or short lead time**		The emphasis in these situations should be on search and rescue if people are exposed if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger (e.g. those on the ground floor). Efforts and resources should also be targeted at ensuring that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. If possible, a flood warning system should be developed.
						Flood warning with adequate lead time and mixed response		The emphasis in these situations should be on ensuring that as many people as possible are warned and know what to do to protect themselves and where to go for safety. Following this, search and rescue should be carried out if this is possible. Proactively, education should focus on flood risk awareness and preparation.
						Partial evacuation following a flood warning		Focus should be on ensuring that as many people as possible are evacuated safely (i.e. with enough time not to be caught in the flooding). Search and rescue operations can then focus on the smaller number of people who remain in the risk area. Efforts and resources should also be targeted at ensuring that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area.
0.5.to 1.1 m^2s^{-1}	High Dangerous for most	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Structural damages and collapse possible for properties with poor quality building fabric	Those outside are vulnerable from the direct effects of from the floodwaters. In addition, those in bungalows will be vulnerable in deeper waters. People will also be afforded little protection in mobile homes and campsites. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse. Vehicles are likely to also stall and lose stability.		**No flood warning or short lead time**		The emphasis in these situations should be on search and rescue if people are exposed if this is possible. Resources should be targeted on identifying the areas or groups of people who are in most immediate danger. Efforts and resources should also be targeted at ensuring that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. If possible, a flood warning system should be developed. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Flood warning with adequate lead time and mixed response		The emphasis in these situations should be on ensuring that as many people as possible are warned and know what to do to protect themselves and where to go for safety. Following this, search and rescue should be carried out if this is possible. Proactively, education should focus on flood risk awareness and preparation. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Partial evacuation following a flood warning		Focus should be on ensuring that as many people as possible are evacuated safely (i.e. with enough time not to be caught out in the flooding). Search and rescue operations can then focus on the smaller number of people who remain in the risk area. Particular efforts should be made to ensure that the population are risk-aware and that they know how to respond when flooding of this magnitude occurs. Where possible ensure that these types of land use are not located in areas that could suffer such severe flooding.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area.
		2. Medium vulnerability (Typical residential area mixed types of properties)	Structural damages – less likely and less severe	Anyone outside in the floodwaters will be in direct danger from the floodwaters. It is here at this point where behaviour becomes significant as structural damages are less likely so those inside should be on the most part protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside where is it not necessary?	**Behaviour dominated**	**No flood warning or short lead time**		During flooding resources should be targeted at assisting the most vulnerable in the community and ensuring that they are safe both before and after flooding and helping them to avoid the risk. Introduction of a flood warning service where possible. If flood warnings are really not possible, attention should focus on ensuring the population is risk aware and know how to respond during flooding.
						Flood warning with adequate lead time and mixed response		Flood warnings should be provided as early as possible to warn as many people as possible. Focus should be on instructing the population on the best course of action to ensure that they act appropriately and get to, or remain in, a place of safety. Resources before flooding should be targeted at raising public awareness of flood risk and how to respond to flood warnings.
						Partial evacuation following a flood warning		Where possible and where there is time people should be encouraged to evacuate. Efforts should be targeted on assisting those who are unable to evacuate themselves. Proactively, efforts should be made to ensure that the population is aware of the risk of flooding and know how to respond during flooding.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		Anyone outside in the floodwaters will be in direct danger from the floodwaters. It is here at this point where behaviour becomes significant as structural damages are less likely so those inside should be on the most part protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside where is it not necessary?		**No flood warning or short lead time**		During flooding resources should be targeted at assisting the most vulnerable in the community and ensuring that they are safe both before and after flooding and helping them to avoid the risk. Introduction of a flood warning service where possible. If flood warnings are really not possible, attention should focus on ensuring the population is risk- aware and know how to respond during flooding.
						Flood warning with adequate lead time and mixed response		Flood warnings should be provided as early as possible to warn as many people as possible. Focus should be on instructing the population on the best course of action to ensure that they act appropriately and get to, or remain in, a place of safety. Resources before flooding should be targeted at raising public awareness of flood risk and how to respond to flood warnings.
						Partial evacuation following a flood warning		Where possible and where there is time people should be encouraged to evacuate. Efforts should be targeted on assisting those who are unable to evacuate themselves. Proactively, efforts should be made to ensure that the population is aware of the risk of flooding and know how to respond during flooding.
						Full evacuation following a flood warning		If a full evacuation occurs, most people will be out of immediate danger. Efforts therefore need to focus on ensuring the well-being of those who have been evacuated from the area.
0.25 to 0.5 m^2s^{-1}	Moderate Dangerous for some	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Structural damages possible for properties with very poor quality building fabric	Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly). They are obviously most vulnerable as they are less able to save themselves from the flood waters and in this category the shelter may not protect them. Motor vehicles may become unstable at these depths and velocities. Those in very poorly constructed properties may also be vulnerable from structural damages.	**People vulnerability dominated though some behaviour-related**	**No flood warning or short lead time**		During flooding resources should be targeted at assisting the most vulnerable in the community and ensuring that they are safe both before and after flooding and helping them to avoid the risk. Introduction of a flood warning service where possible. If flood warnings are really not possible, attention should focus on ensuring the population is risk-aware and know how to respond during flooding.
						Flood warning with adequate lead time and mixed response		The warning should be concentrated on raising awareness of the potential for danger and in particular at those most likely to be exposed to the flood waters (e.g. water-related recreational activities). Resources should be targeted to assist the most vulnerable groups. Education should also be focussed on informing people about the dangers of certain activities (e.g. driving or swimming).
						Partial evacuation following a flood warning		Evacuation efforts should target those most vulnerable in these areas and ensure that they are assisted to leave the area or moved to more secure locations. Resources should be used to ensure the well-being of those who have been evacuated as well as those who remain.
						Full evacuation following a flood warning		An unlikely scenario for this type of risk level. Resources should be concentrated on evacuating and assisting those most vulnerable, particularly in this zone where there is limited shelter.
		2. Medium vulnerability (Typical residential area mixed types of properties)	Unlikely	Only the most vulnerable should be in direct danger from the floodwaters (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.		**No flood warning or short lead time**		During flooding resources should be targeted at assisting the most vulnerable in the community and ensuring that they are safe both before and after flooding, and helping them to avoid the risk. Introduction of a flood warning service where possible. If flood warnings are really not possible, attention should focus on ensuring the population is risk-aware and know how to respond during flooding.
						Flood warning with adequate lead time and mixed response		The warning should be concentrated on raising awareness of the potential for danger and in particular at those most likely to be exposed to the flood waters (e.g. water-related recreational activities). Resources should be targeted to assist the most vulnerable groups. Education should also be focussed on informing people about the dangers of certain activities (e.g. driving or swimming).
						Partial evacuation following a flood warning		Evacuation is unlikely to be needed in this scenario as the risk to people is low. There may be the need to target specific groups who may be at risk (e.g. old people's homes or schools). Moving vulnerable people like the elderly may have adverse long-term impacts.
						Full evacuation following a flood warning		An unlikely scenario for this type of risk level. Resources should be concentrated on evacuating and assisting those most vulnerable. Attention should then be turned to assisting in the protection and clear-up operation of those whose properties have been flooded.
		1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.		**No flood warning or short lead time**		During flooding resources should be targeted at assisting the most vulnerable in the community and ensuring that they are safe both before and after flooding, and helping them to avoid the risk. Introduction of a flood warning service where possible. If flood warnings are really not possible, attention should focus on ensuring the population is risk-aware and know how to respond during flooding.
						Flood warning with adequate lead time and mixed response		The warning should be concentrated on raising awareness of the potential for danger and in particular at those most likely to be exposed to the flood waters (e.g. water-related recreational activities). Resources should be targeted to assist the most vulnerable groups. Education should also be focussed on informing people about the dangers of certain activities (e.g. driving or swimming).
						Partial evacuation following a flood warning		Evacuation is unlikely to be needed in this scenario as the risk to people is low. There may be the need to target specific groups who may be at risk (e.g. old people's homes or schools.) Although it must be remembered where the risk is low, moving vulnerable people like the elderly may have an adverse impact upon long-term health. Resources should be used to ensure the well-being of those who have been evacuated as well as those who remain.
						Full evacuation following a flood warning		An unlikely scenario for this type of risk level. Resources should be concentrated on evacuating and assisting those most vulnerable.
<0.25 m^2s^{-1}	Low Caution	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties) **2. Medium vulnerability** (Typical residential area mixed types of properties) **1. Low vulnerability** (Multi-storey apartments and masonry concrete and brick properties)	Unlikely	A very low risk to adults either out in the open or who is in a property. There may be a threat to the stability of some vehicles even at these low depth-velocity factors.	**Low risk**	In terms of risk to life flood warnings and evacuation will have little impact as there is a low risk to life from the event itself, though a flood warning may be used to ask people to exercise caution and take action to reduce damages.		There may be the need to target specific groups that may be at risk (e.g. old people's homes or schools) though most actions will be by warning people to be cautious around the floodwaters.

Figure 2.6: Threshold approach to assessing Risk to Life from flooding in Europe

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[1] The mid-range values are presented here. .
[2] Four different mitigation variables are presented in the model.
[3] The actions provided here are indicative. If possible, these should be tailored to the local situation and circumstances.

2.8 Application of the threshold European Risk to Life model to the European flood event data

The model (Figure 2.6) should be applied by working from left to right, and users should firstly identify the depth and velocity characteristics of the area of interest to them and select the level which best matches the depth-velocity products estimated for their area. It is then necessary to assess an area's vulnerability, by examining the land use, type and quality of buildings and whether there are any particularly vulnerable groups of people present. Additionally, it may be necessary to assess whether large numbers of people are likely to be vulnerable in motor vehicles, for instance if a major road crosses the zone of interest. By selecting the hazard and then the vulnerability, an initial assessment of the level of risk for an area is then presented in the column *Risk to life categories without mitigation.* A user can then select which flood warning or evacuation category is likely to be present within this area and therefore assess the resulting risk to life once this has been applied, as mitigating actions may have the effect of reducing the risk.

Following this example, it is useful to apply the model to some of the flood events that have been explored within this study. It must be remembered however, that applied in this way on an event basis the approach will suffer from similar zoning problems to when the *Risk to People* methodology is applied as it will necessitate the averaging of different events. For instance, the Boscastle event is considered to have a high risk level and therefore a high potential for loss of life, yet fatalities were prevented because of the rescue efforts by the authorities. Conversely, there were a large number of fatalities in Troubky because many building collapses in relatively low depths and velocities. These results indicate the complexity of the issues involved when trying to assess the risk to life and it is difficult for any model to capture all of these and represent or predict exact numbers of fatalities. A range of different types of flooding events and events of different outcomes is illustrated in Table 2.6.

Table 2.6: Application of the threshold model to European flood events

Flood event	DxV m^2/s	Area Vulnerability	Mitigating factor	Risk Level	Event Deaths	Description
Boscastle, UK	2	Medium	No flood warning	High	0	The threat of risk to life is high, but deaths were averted due to the efforts of search and rescue, with around 100 people airlifted to safety.
Carlisle Zone D, UK	2	Medium	Flood warning and some evacuation	Medium	2	The two deaths in the Carlisle event were due to People Vulnerability as they were two elderly women living alone who died in their own homes who were not warned and were not assisted in evacuating from their homes.
Troubky Czech Republic	0.6	High	Flood warning	High	9	Although the risk in this category is high the main factor was the very poor building fabric. Deaths caused due to collapsed buildings constructed from materials not resilient to flood waters. When buildings do collapse the deaths from flooding increase greatly. The majority of the people who died were elderly therefore this appears to reflect the people vulnerability-dominated deaths at this level
Klodzko Town A	20	High	Flood warning	Extreme	1	Victim was killed by direct contact with the flood waters. It was argued that many people heeded the warning and avoided venturing outside. In addition, there were no instances of building collapse.
Calogne	1	Medium	Partial evacuation	Low	1	A 75 year-old woman drowned in the channel. Therefore the death in this case is related to both people vulnerability and behaviour-related as the majority of the people close to the channel were evacuated.
Cambrils, Spain	3	Medium	Flood warning	High	3	All three deaths in this incident were behaviour related as they unnecessarily drove their car onto a flooded road.
Eilenburg, Germany	8	Low	Full evacuation	Medium	0	Deaths avoided by action of effective warning and evacuation

2.9 Risk to Life mapping

A GIS methodology for mapping risk to life using the new model was developed and tested with case study data. A hazard map of the depth-velocity product is created using modelled depths and velocities that are expected to be experienced during flooding. The vulnerability map contains three levels of information: the vulnerability level, the population component and also the mitigation factor. The population component and the mitigation factor are considered as additional information and do not necessarily affect the spatial extent of the features. It is thus mainly the nature of the area that defines the features boundary and the vulnerability scale. The model is based on the type of buildings that could be found in an area. Spatial information usually available includes the type of land-use, such as residential area, industrial and commercial units, recreational area, open field, etc. The vulnerability could change depending on the activities within an area e.g. the presence of schools, hospitals or care homes.

The user can change, if necessary, the hazard threshold values and the risk impact factor to calibrate the model. The results of the model could be mapped with different indicators. The risk level defines for each area the level of the risk to life based on a scale of four qualitative values (low to extreme) and is calculated using the thresholds and approach defined in the model. The exposure factor gives the potential number of people exposed to the risk multiplied by the risk factor associated with a risk class. It could be expressed per ha (as shown in Figure 2.7) illustrated with one of the case studies from the Milestone report (T10-07-10), Thamesmead, London). From top to bottom, the hazard map and vulnerability map are spatially unified and are used as an input to the risk to life model. Risk level and exposure factor are the resulting map of the model.

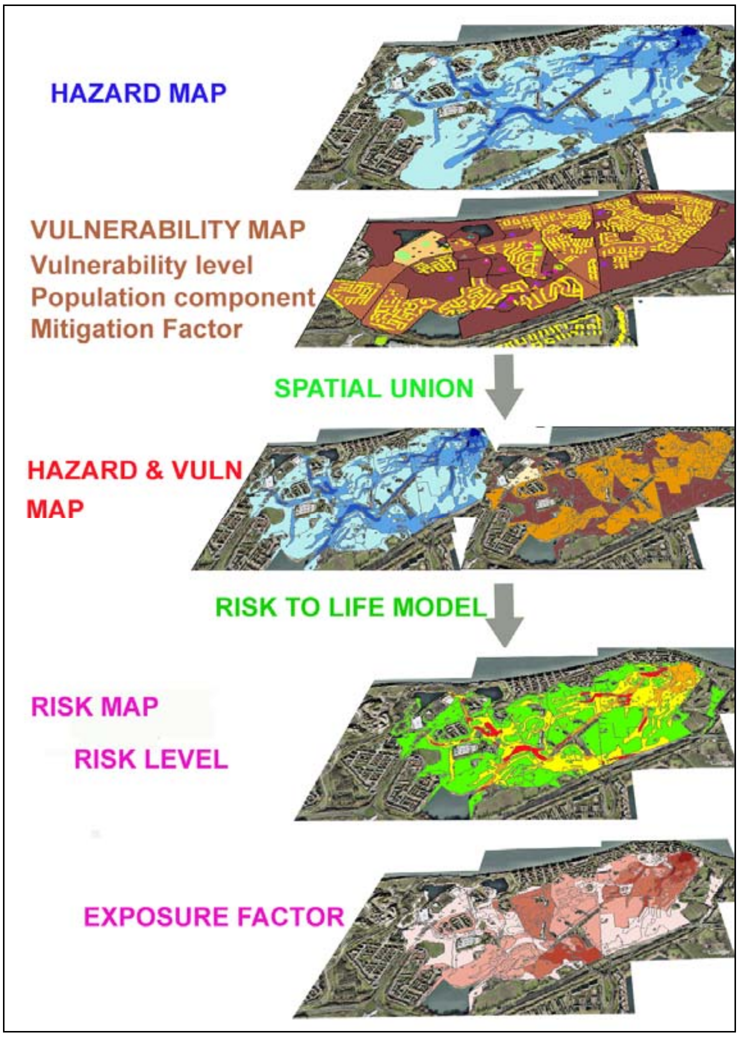

Figure 2.7: Mapping Process applied to the Thamesmead UK case study.

3. Relevance to practice

A new semi-quantitative 'threshold' model which combines hazard and exposure thresholds and mitigating factors has been developed to assess risk to life from river flooding in a wider European context. The model has been designed to be flexible enough to be used and applied at a range of scales, from a broad assessment at a regional or national scale, to a more detailed local scale. This flexibility is essential as not all European countries have detailed flood data that is readily available. The model should be used as a tool to allow flood managers to make general and comparative assessments of risk to life and to consider the targeting of resources before, during and after flooding. The new model also permits simple mapping of risk to life which again can be applied at various scales. The model has been developed using data from fluvial flood events and therefore caution is needed when applying the approach to other types of flooding.

It is recognised that flooding can occur on a wide scale stretching often limited resources and personnel. Therefore, different flood risk zones should not be examined in isolation, their risk needs to be assessed and the outcome integrated into a broader and comprehensive action plan. One advantage of this scaled approach over the methodology applied in the *Risk to People* model is that although it is still necessary to zone at-risk areas according to hazard characteristics and vulnerability, it is not necessary to zone them homogenously for both features. Therefore, areas of differing hazard and areas of differing vulnerability can overlap and intersect and a risk level can be assessed for each different combination

It is acknowledged that the new Risk to Life model and its thresholds need to be tested further on a range of different flood events to investigate the validity of the approach, and in particular the thresholds selected. Despite this, it is hoped that this approach permits an initial assessment and prediction of the risk to life which can subsequently be enhanced and refined with local knowledge. Thus when applying the model at a high resolution, it is also recommended that the approach is used iteratively, with users applying their own knowledge and experience to tailor the categories and what they contain to their local specific situations. The approach also permits some scope for uncertainty, in particular within the depth and velocity data. The model will of course be most sensitive to error at the thresholds of the different depth-velocity product classes.

Overall, the research has increased the understanding of the factors surrounding fatalities from flood events in the broader European context. It has also highlighted the potential roles of factors such as building collapse, human behaviour and the role of chance in affecting fatalities and injuries, as well as the benefits of mitigating measures such as evacuation and flood warnings.

4. Remaining gaps in knowledge

Several recommendations can be made to take this research forward.

- In order to refine the model further good quality data from many more flood events is required than were available for this research. To facilitate the data collection, this would need the cooperation of European governments and agencies in making data available rather than having to purchase it on a commercial basis.

- The EU has recognised the need for greater European co-ordination on flood risk management, therefore it is suggested that protocols are needed to address the data issue. Moreover, any future research project that requires the collection of such data at a European scale needs to allow sufficient time and resources, and requests for data need to be made well in advance of when it is actually needed.

- In particular, more data from slow-rising flood events needs to be collected and analysed to further identify factors impacting upon risk to life in these situations.

- A further suggestion could be to produce separate risk to life models for different types of flood events e.g. flash floods (for both urban and rural areas), slow rising floods, coastal floods, dam or dike break or breaching etc., although this would again require large amounts of data. It must be remembered that this approach has only been developed for fluvial flood events.

- Exploratory research with flood risk managers, local authorities and other stakeholders across Europe could initially be conducted in order to assess the type of information and models that would be of most use in different situations. This could then form the basis for taking the research forward to produce practical and easy to use tools that are fit for purpose and which take account of available resources.

- In order for the mapping methodology to be effectively operationalised more work is needed. This will include calibrating the model with real events e.g. testing it using comparisons of different events, of population scenarios and of warning and evacuation scenarios. Participatory processes at case study sites would be highly relevant to identify vulnerability areas, to build scenarios and to ground-truth the model.

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