Integrated Flood Risk Analysis
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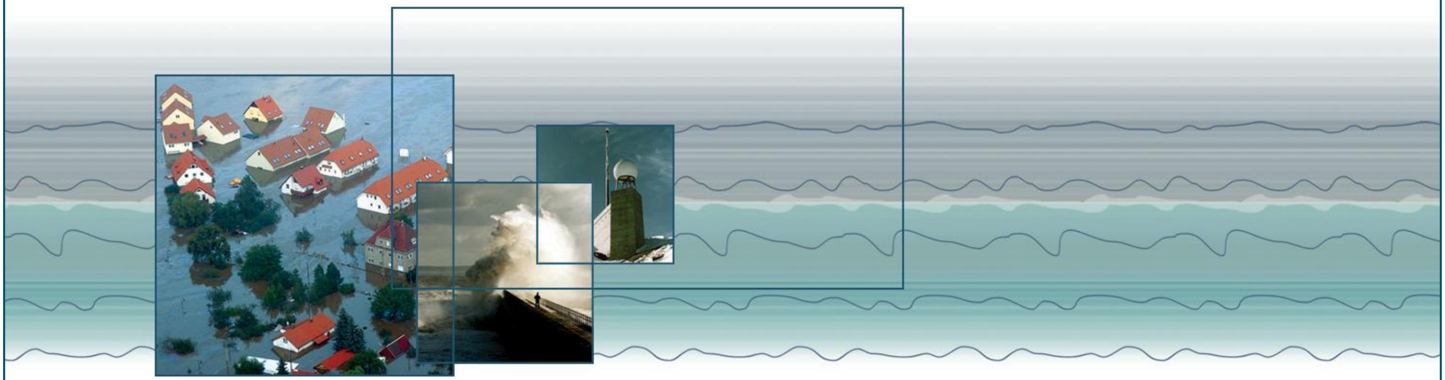

Building a model to estimate Risk to Life for European flood events – Final Report

Date **November 2007**

Report Number **T10-07-10**
Revision Number 1_6_Pn10
M10.1

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FLOODsite is co-funded by the European Community
Sixth Framework Programme for European Research and Technological Development (2002-2006)
FLOODsite is an Integrated Project in the Global Change and Eco-systems Sub-Priority
Start date March 2004, duration 5 Years

Document Dissemination Level

PU	**Public**	**PU**
PP	Restricted to other programme participants (including the Commission Services)	
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CO	Confidential, only for members of the consortium (including the Commission Services)	

Co-ordinator: HR Wallingford, UK
Project Contract No: GOCE-CT-2004-505420
Project website: www.floodsite.net

SIXTH FRAMEWORK PROGRAMME

DOCUMENT INFORMATION

Title	**Building models to estimate risk to life for flood events**
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Distribution	**Public**
Document Reference	**T10-07-10**

DOCUMENT HISTORY

Date	Revision	Prepared by	Organisation	Approved by	Notes
07/09/07	1_0_Pn10	S. Priest, T. Wilson	FHRC/MU	S.Tapsell	
18/09/07	1_1_Pn10	S. Tapsell	FHRC/MU	S.Priest	
23/10/07	1_2_Pn10	S. Priest	FHRC/MU	S.Tapsell	
30/10/07	1_3_Pn10	S. Priest	FHRC/MU	E.Penning-Rowsell	
30/11/07	1_4_Pn10	S. Tapsell	FHRC.MU		
10/11/08	1_5_Pn10	S. Priest	FHRC.MU		
09/03/09	1_6_Pn10	S. Priest	FHRC.MU		Minor changes to Disclaimer

ACKNOWLEDGEMENT

The work described in this publication was supported by the European Community's Sixth Framework Programme through the grant to the budget of the Integrated Project FLOODsite, Contract GOCE-CT-2004-505420.

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SUMMARY

The research carried out for Activity 1 of Task 10 focuses on developing a methodology to estimate loss of life from flood events. In order to reduce the risk to life 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. A number of problems were identified with the current model when applied to the flood data collected from Continental Europe. In particular the model was not designed for the major rivers and mountainous catchments compared with the UK and thus resulted in dramatic over-predictions of injuries and fatalities. Moreover, the model was found to contain several structural weaknesses. Research conducted into the factors surrounding European flood fatalities also highlighted the importance of institutional arrangements and mitigating factors such as evacuation and rescue operations. Finally, the UK model was seen to be hugely sensitive to people vulnerability, which in much of the wider European flooding is arguably of less importance in than it is in the UK.

Thus a new semi-qualitative 'threshold' model which combines hazard and exposure thresholds and mitigating factors has been developed to assess risk to life from 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. It is envisaged that 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.

Two additional reports are also related to Task 10. The first is a case study of the 2002 flooding in the Gard region of France (Lutoff and Ruin, 2007) and is based on research conducted for a PhD thesis (see Ruin 2007; T10-07-11). The second report (Tapsell *et al*., 2008) focuses on understanding the complex health impacts of floods and presents a conceptual model of the various factors impacting human health and well-being with respect to flooding (FLOOD*site* Project document T10-09-02). This research was originally intended to be a part of the work for the Risk to Life model in Activity 1, but on reflection it was decided that it should be reported separately.

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1. Introduction

1.1 Background and Context

Floods are some of the most frequently reported and costly natural disasters world-wide (Hewitt, 1997). The extent of flooding is expected to increase over the next 50 to 100 years owing to the effects of climate change and global warming (IPCC, 2007; Stern, 2007). As a result of this, regional changes to flood distribution may mean that areas not previously affected by flooding may become newly afflicted (Few, 2006). In Europe in particular, the incidents of major flooding have shown an upward trend over the last 15 years, with more recent years (e.g. 2000, 2002 and 2005) recording particularly high numbers of flood events (www.em-dat.net). However, the flood situation across Europe is complex depending on variations in topography, hydrology, geomorphology, spatial development and climate among other factors, along with respective institutional response systems.

Moreover, floods may result from a range of different causes, for example, intense or prolonged rainfall, snow and ice melt, tidal surges, dyke failure, incapacity of drainage systems, and rising groundwater. Some flood events may even involve a combination of one or more of these types of flooding (e.g. fluvial and tidal) further complicating the situation. In addition, floods may be fast onset e.g. within an hour or two in rapid response catchments, or slow onset over many hours or even days in the lower floodplains. These differences in the type of flood events can have serious implications for the risk to human life. For example, in England and Wales river floods have been typically small-scale, short-lived and shallow resulting in few deaths, while in other parts of continental Europe where the river systems are much larger, such as Germany, flooding may be deep and spread over large areas and last for many days or weeks posing greater risk to life. In northern Italy, floods in the mountainous areas may pose additional problems as they may contain large amounts of mud and other large debris.

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. It is believed that many of the cases of loss of life could be prevented or reduced if adequate warning and response systems were in place. However, in order to reduce the risk to life 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 may be effective.

1.2 Aims of Task 10 Activity 1: Building models to estimate loss of life and health impacts for flood events

The results outlined in this Milestone report comprise the outputs from Activity 1 of Task 10. The overall objective of Task 10 of the FLOOD*site* project is to focus research efforts on innovative methods to understand, model and evaluate flood damages. One aspect of this damage relates to risk to life and serious injury resulting from flooding. The objectives of Activity 1 are therefore as follows:

- to further develop a model, or models, that will 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.

It is further 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 and health impacts related to fluvial flooding. Coastal or other types of flooding have not been included due to time and funding constraints.

1.2.1 European Floods Directive

The above objectives also directly relate to the European Directive on the Assessment and Management of Flood Risks (EU 2007/60/EC of 23 October 2007). In particular, the research addresses the Directive in a number of ways as follows:

- Article 1: by contributing innovative evaluation and modelling methodologies "aiming at reduction of the adverse consequences for human health … associated with floods in the Community".
- 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".
- Article 4 (2d): by providing "an assessment of the potential adverse consequences of future floods for human health".
- 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, and other factors.

1.3 Structure of the report

The remainder of the report is structured in the following way. Section 2 provides a review of the literature relating to risk to life in floods and examines the different factors affecting cause of death or injury. It also outlines different methods to calculate flood risks to people and includes a summary of the various sources of information used. In Section 3 the UK 'Flood Risks to People' methodology is explained along with its application to date and adaptations of the model carried out for this research. The methodology used for this research is outlined in Section 4 along with the limitations and problems arising from data collection. Section 5 analyses the circumstances and causes of European flood-related deaths, and includes a further case study of flooding in the Gard region of France in 2002; the Section ends with recommendations for refining the UK model.

Section 6 comprises a case study of the application of the Flood Risk to People model to the flooding in Boscastle, UK, in 2004. This highlights the implications and limitations for using the current *Risk to People* methodology in the wider European context. These limitations are then further explored in Section 7 which discusses the calibration of the *Risk to People* model with data from a number of European flood events. Adaptations and revisions to the current UK model are discussed in Section 8 which also explains the data analyses that were conducted. A proposed European Risk to Life model is outlined in Section 9, while Section 10 focuses on approaches for mapping the risk to life. The final Section draws together the key research findings along with recommendations for further research.

The report thus comprises a detailed and systematic description and discussion of the research carried out. Readers who are not interested in reading a step by step rationale and analysis of the research are guided to Section 9 which outlines the new Risk to Life model developed for this study; however, this may result in a limited understanding of how the model has been developed.

2. Review of the Literature

During the twentieth century the frequency of major floods worldwide appear to have increased substantially (Milly *et al*., 2002; Kundzewicz and Kundzewicz, 2005). The frequency and extent of flooding worldwide, and the accompanying impacts, are expected to increase even further over the next 50 to 100 years owing to the effects of global warming (IPCC, 2007) and factors such as disparities in wealth and access to resources (Evans *et al.*, 2004). Floods may cause hundreds or thousands of deaths every year in developing countries. In developed countries people have come to expect to be protected from flooding and have become less aware of the potential risks and likely impacts of living within a floodplain or in a flood risk area, and are subsequently often unprepared when floods strike. In Europe, although the numbers of deaths from floods are not as high as in other parts of the world, flooding is the most common natural disaster, and deaths are not uncommon (WHO- Europe, 2002a); much flood risk management effort is therefore aimed at reducing these losses.

This review of literature begins by identifying the possible factors leading to risk to life and information on the relation of risks to people and hazards. It outlines various methods to calculate flood risks to people and leads on to the *Risk to People* methodology to be tested within this study.

2.1 Sources of information

A number of sources have been used whilst compiling this literature review. Existing research relating to risk to life and injury conducted by FHRC and others was initially consulted, and the Flood Hazard Research Centre's own library provided a number of references. In order to update the existing data other papers were obtained by following up key references found in some of the literature reviewed. Journal article databases such as Ingenta and Web of Knowledge were searched using key words such as 'flood and fatalities', 'flood and victim', 'flood and injury', 'loss of life and flood', 'floods Europe'. Further Internet searches were conducted using similar key words and provided several useful reports and other non-refereed documents. Finally, several searches were undertaken using 'EM-DAT': The OFDA/CRED International Disaster Database (www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium), which provided useful information on flood events, the number of fatalities and people affected by country, date and type of disaster.

2.2 Floods and risk to life or injury

Recent floods in Europe have resulted in a number of fatalities. For example, in August 2005 at least 50 people died, 33 of them in Romania, due to flooding caused by heavy rains in Austria, Bulgaria, Germany, Romania, and Switzerland (www.em-dat.net[1]). Although not as widespread in nature, flooding also affected parts of Europe in 2006 with a reported 47 fatalities in Romania between April and July (www.em-dat.net[1]). Europe suffered eight major floods from January to July 2002 that killed 93 people and affected 336,000. The August 2002 floods in Central Europe caused more than 100 fatalities in Austria, the Czech Republic, Germany, Hungary and the Russian Federation (WHO-Europe, 2002a). The 1997 Oder floods were the largest floods on record in Poland (Kundzewicz *et al.*, 1999) and caused 50 deaths (Kundzewicz and Kundzewicz, 2005). Guzzetti *et al.* (2005) highlight that floods and landslides kill people almost every year in Italy and 146 have been reported to have died from flooding since 1990 (www.em-dat.net[1]). Examinations of media reports suggest the summer 2007 flooding in England and Wales caused 10 deaths (both directly and indirectly), as two separate periods of flooding in June and July affected large areas.

[1] In order for an event to be recorded into the database, at least one of the following criteria must be fulfilled: 10 or more people killed, 100 or more people affected/injured/homeless, significant disaster, e.g. 'worst disaster in the decade', significant damage, e.g. 'most costly disaster'. Source: www.em-dat.net Data Accessed 22/01/07

No protection work can provide one hundred percent security against flooding. Floodplains are among the most densely populated areas in the world. People often have faith in flood defences which can result in a false sense of security, however the higher the defences the more disastrous the consequences if they are overtopped or breached (Alkema, 2003). Floodplains are areas particularly well suited for development as they are flat, near water resources and easy to develop with roads and water and power networks (Kron, 2002). Climate change and the associated shift in seasonal rainfall patterns and higher weather variability is another factor which is likely to lead to more extreme events (Kron, 2002; Kundzewicz *et al.*, 2005).

Kundzewicz *et al.* (2005, p.167) cite the following changes as possible reasons for the increase in flood risk and vulnerability in Central Europe:

- Changes in terrestrial systems, both hydrological systems and ecosystems, land cover change, river regulation: straightening of channels, embankment, changes in the conditions that transform precipitation into run-off causing a higher peak and shorter time-to-peak.
- Changes in socio-economic systems, increasing exposure and potential damage due to floodplain development, higher wealth in flood prone areas, land use changes such as deforestation, developments, elimination of natural inundation areas such as wetlands and natural floodplains, changing risk perception.
- Changes in climate, such as increase in the intensity of precipitation, seasonality, circulation patterns.

Jonkman and Kelman (2005, p.76) define flood fatality or flood-related fatality as '*a fatality that would not have occurred without a specific flood event'* although they accept that this definition raises questions regarding the timing of the death. They also define 'flood' as '*the presence of water on areas that are usually dry*'. Instead of referring to 'direct' or 'indirect' fatalities, they divide the flood event into three phases: pre-impact, impact and post-impact. In the study, 87% of a total of 247 flood fatalities occurred during the impact phase.

The Emergencies Disaster Database (EM-DAT: The OFDA/CRED International Disaster Database (www.em-dat.net[1], Université Catholique de Louvain, Brussels, Belgium) records a total of 2,516 flood disasters in the period 1980- 2006, accounting for 176,824 deaths and some 2,600 million people affected world-wide (see Appendix A). These figures do not include tsunamis or hurricane victims, even though according to Jonkman and Kelman's (2005) definition of flood they should be included as 'flood victims'. Nine out of ten fatalities caused by hurricanes are deaths associated with flooding or storm surges (Noji, 1993). For instance, victims of Hurricane Katrina or the December 2004 Asian tsunami are not included in the EM-DAT database under flooding. There are consistency problems when classifying flood deaths (Jonkman, 2003) as no one "standardised universally-accepted method exists for determining whether deaths are caused by a natural disaster" either directly or indirectly (Schlenger *et al.*, 2006, p12). Kelman (2003) highlights the difficulty of attributing certain deaths to a flood event and Noji (1993) reports the same issue regarding hurricane deaths. Guzzetti *et al.* (2005) compiled a database of floods and landslides in Italy between 1279 and 2002 and found that the numbers of injuries recorded are low compared to the numbers of deaths. This was both due to human vulnerability to these events but also to the imprecision or lack of information on the number of injuries.

Research into causes of death from floods and related circumstances is necessary to improve the prevention of fatalities (Jonkman, 2003). Drowning is not the only cause of death in a flood and many of the drownings are car related, as discussed in the following sections. It is impossible to avoid all flood deaths, however, there are many pre, during and post event deaths that are probably preventable (Duclos, 1987). Although, in general, mortality in floods has not been curbed, there has been a tendency towards a decrease in the number of flood-related fatalities per flood event. Kundzewicz and Kundzewicz (2005) argue that this is a sign that flood preparedness and warning systems are saving lives.

2.3 Factors affecting cause of death or injury

Mortality and morbidity can depend upon the type of flood event and various other factors. The main health concerns in slow rising and long duration floods are communicable diseases, adequate sanitation, water and food supplies, nutrition and risks from vector populations such as mosquitos. In Europe and developed countries these risks are generally low but are likely to increase in the future with global warming. In flash floods and other situations where the impact is more immediate, most deaths are due to drowning while injury is usually a result of moving debris and high winds (Legome *et al.*, 1995). Mortality associated with a flood will depend on the flood characteristics (e.g. depth, velocity and speed of onset) but the way people respond to floods is a critical factor. In European floods particularly, deaths are strongly related to risk-taking behaviour (Jonkman, 2003) and the World Health Organization (2002a) estimate that up to 40% of health impacts due to flooding result from such behaviour.

Jonkman and Kelman (2005) propose a framework for analysing flood deaths: they suggest that a combination of hazard factors and vulnerability factors result in a flood death due to a specific medical cause (e.g. physical trauma, drowning, heart attack). Flood hazard factors used to calculate how floods impact upon people include depth of water, rate of rise, velocity, wave characteristics and debris and pollutants load (Jonkman and Kelman, 2005). The meteorological conditions that accompany floods can also cause additional deaths, for example, in car accidents due to more collisions and falling trees by high winds (Jonkman, 2003). Injuries and deaths may also occur during clean up (Noji, 1993; MMRW, 1989).) or as a result of undertaking rescues (Jonkman and Kelman, 2005; MMRW, 2000). Rescues from fast flowing waters in particular present high hazards.

Risk to life or serious injury is thus likely to be greatest when one or more of the following flood conditions exist (HR Wallingford, 2003, p.5):

- flow velocities are high
- flood onset is sudden as in flash floods, for example the Lynton/Lynmouth floods, UK, in 1952, Big Thompson flood, USA, in 1976 and flash floods in Southeast China in 1996. This includes the fast arrival time of floodwaters from the source of flooding (e.g. defence breach) to human settlements (Jonkman, 2007)
- flood waters are deep
- extensive low lying densely populated areas are affected, as in Bangladesh, so that escape to high ground is not possible
- no effective warning is received (i.e. where there is less than, say, 60 minutes of warning)
- flood victims have pre-existing health/mobility problems
- flood alleviation and other artificial structures themselves involve a risk to life because of the possibility of failure, for example dam or dike failure
- poor flood defence assets lead to breaches or flood wall failure, leading to high velocities and flood water loadings on people in the path
- debris in the floodwater that can cause death or injury
- flood duration is long and/or climatic conditions are severe, leading to death from exposure
- poor quality of buildings, which determines the possibility of building collapse (Jonkman, 2007)

Certain characteristics of people, their community or property can also increase the risk to life of those affected by flooding. These characteristics include (among others) the presence of elderly or ill people, particular types of property (e.g. single storey), no previous experience or awareness of flooding, poor community support, the need to evacuate and live in temporary accommodation (HR Wallingford, 2003). Vulnerabilities that can potentially lead to a flood death include age, gender, prior health and disability (physical and mental), swimming ability, previous flooding experience, clothing, activity and behaviour (e.g. sleeping, attempting a rescue, evacuation), impairment (e.g. due to alcohol or drugs) and knowledge of the area. Although the medical cause of death is usually listed, the fundamental cause of death is the flood. The literature reviewed by Jonkman and Kelman (2005) rarely makes links between hazard factors, individual vulnerabilities and the medical cause of death.

There are also circumstances which may contribute to reduce the death toll caused by a flood. In 1988, a flash flood in the region of Nimes, France, damaged 45,000 homes and destroyed more than 1,100 vehicles. However, there was a relatively low number of deaths (9) and serious injuries (3) reported. In addition, only 17% of the population surveyed were aware that they lived in a flood prone area. The low number of deaths can be attributed to the fact that the flood occurred early in the morning when people were still at home and that, before the peak of the flood, water was already blocking traffic on the roads. The limited death toll was also attributed to the mild temperature, official rescue operations and rescues by civilians. The participation of the army in the cleanup operations together with the distribution of boots and gloves to other workers seems to explain the low numbers of injuries that occurred during this recovery phase (Duclos *et al.*, 1991).

Thus three broad sets of flood characteristics were identified in HR Wallingford (2003) which are seen to influence the number of fatalities or injuries in the event of a flood:

- Area characteristics (inside/outside building, nature of housing, flood warnings)
- Flood characteristics (depth, velocity, etc.)
- Population characteristics (age, health, etc.)

Loss of life is caused by a combination of the above characteristics, for example a high depth and velocity, coupled with vulnerable housing and no flood warning. Identifying the relationships between the different variables is one of the problems with modelling loss of life (Jonkman *et al.*, 2002). These characteristics are discussed in more detail below.

2.3.1 Area characteristics

Area characteristics can determine the local topographical, geological and hydrological conditions and catchment characteristics, as well as local climate, land use and spatial development. For example, they can affect the speed of onset of flooding. Floods in areas with steep hillsides and ‘flashy’ catchments are difficult to warn against and prepare for and can be particularly dangerous due to mudslides and the amount of debris in the floodwaters (Environment Agency, 2005a). Therefore, the hydraulic and topographic characteristics of an area will affect the nature of a flood event, particularly the depth and velocity of the floodwaters. Factors such as the presence of trees, caravans and other sources of large debris also depend upon the type of area where the flood event occurs.

Threat to life and injury will depend on the hydraulic characteristics of a river, coast and its floodplain as well as on the magnitude of the flood event (Defra/Environment Agency, 2003; cited in HR Wallingford, 2003). The depth and velocity of a flood varies with distance from the river, coast or other source of the flood. This in turn will depend on the topography of the floodplain and the presence of obstacles. Hence, knowledge of the floodplain is essential when estimating flood depths and velocities (HR Wallingford, 2003). The nature of the floodplain may also affect evacuation, for example in some urban areas access to residents may be lost early in the flood due to the floodwaters blocking roads (Defra/Environment Agency, 2003; cited in HR Wallingford, 2003).

New building developments in a flood prone area can affect the consequences of a flood by changing the topography and thus the effects on people and property in the inundated area. This issue is discussed by Alkema (2003) in the study of the development of a new motorway in a highly populated area in the Adige valley, Italy. Also, in flooded urban areas, people attempting to move about, particularly where flood waters are turbid or discoloured, may fall down blown manholes, into excavations or into ditches (HR Wallingford, 2003).

One key factor affecting risk to life is the existence of a flood warning system, which in turn will depend on the type of flood. Slow rising floods can afford up to several days of warning, but flooding can also occur very quickly in the event of a flash flood or dam break, limiting the amount of time to issue a warning (HR Wallingford, 2003). However, the proportion of people that receive a warning can be extremely low, for instance only 5% of the people surveyed after the 1997 floods in Poland had received an official warning (Bogdanska-Warmuz, 2001).

The location of people during a flood is also influenced by a number of factors such as the time of the day or time of year of the flood. Particularly in the absence of an official flood warning system, the timing of the onset of the flooding is likely to be significant to whether people are aware of waters rising, or indeed of any heavy precipitation, and therefore are aware of the danger. If a flood event begins in the middle of the night a flood might be reaching hazardous levels before some people are aware, which may affect their options and their ability to react. This is obviously more important when considering fast flowing, rapid onset flood events. The time of day will also affect whether people are at home or at work, which can lead to an increase or decrease in the numbers exposed, depending upon where the flooding occurs. For instance, if a flood occurs during the evening or at a weekend, more people are likely to be in their homes, whereas a daytime flood during the week will mean that many people are at their workplace. However, generally the working population will be younger and able-bodied and therefore would be present to assist others to safety.

The seasonality of the flooding is also important. In those regions which experience large numbers of visitors (in either summer or winter months) not only will this mean that flooding at this time of year potentially impact upon more people, but might also affect those with a lower awareness of the risk, those who have a more limited understanding of how to respond and potentially present language difficulties (causing problems for both warning and response). Some people also might be participating in activities which would inherently make them more vulnerable to flooding should a rapid-onset event occur (e.g. fishing, canoeing, and camping). It has also been argued (Jonkman and Kelman, 2005; Poole and Hogan, 2007) that in some circumstances the seasonality will affect the ability of people to escape floodwaters or indeed directly cause their death. The temperature of the water and/or the surrounding air temperature for those displaced, and having to spend significant time outside, may increase the instances of mortality. Poole and Hogan (2007) argue that since flood waters are mostly well below the core temperature of the body, hyperthermia through prolonged exposure to the flood waters could occur in any season.

2.3.2 Flood characteristics

As previously mentioned above, flood depth and velocity are the main characteristics of a flood that affect loss of life and injury (e.g. HR Wallingford, 2005a; HR Wallingford, 2003; Jonkman *et al.*, 2002; Dekay and McClelland, 1993). Loss of life and injury are expected to increase when flood waters are deep and fast flowing. Debris in floodwaters presents an added threat to people and buildings especially in fast flowing waters (HR Wallingford, 2005a; HR Wallingford, 2003). The presence of debris depends on the main land use of the area for example whether an area is rural or urban. Examples of possible large debris include rocks, trees, caravans, and cars.

2.3.3 Dwelling characteristics

The characteristics of people’s individual dwellings may be significant factors affecting risk to life during flood events. Floods can have a damaging affect on buildings which, if the building collapses, may cause fatalities (Jonkman, 2003). Damage to buildings caused by a flood depends on a series of circumstances. The main factors are the flood characteristics (depth, velocity, presence of debris) and those characteristics of the buildings being affected (number and structure of buildings) (Roos, 2003).

As part of the RESCDAM project Karvonen *et al.*(2000) conducted a review of literature regarding the permanence of buildings in flowing waters. The following Table 2.1 shows the flood conditions that would cause total or partial structural damage to buildings.

Table 2.1: Flood conditions leading to the partial or total damage of buildings

House type	**Partial damage**	**Total damage**
	vd = velocity x depth	
Wood framed- unanchored	$vd \geq 2\ m^2/s$	$vd \geq 3\ m^2/s$
Wood framed-anchored	$vd \geq 3\ m^2/s$	$vd \geq 7\ m^2/s$
Masonry, concrete and brick	$v \geq 2$ m/s and $vd \geq 3\ m^2/s$	$v \geq 2$ m/s and $vd \geq 7\ m^2/s$

Source: Karvonen *et al.* (2000, p.18)

The failure of walls and the scour of foundations were the most relevant failure mechanisms identified for Dutch properties affected by flooding by Roos (2003). Velocity and depth damage curves derived by Roos' model showed that 'failure of walls' would cause the most damage. The flood factor that has the greatest effect on the failure of walls is the debris load. Wave action did not cause damage at all and velocity and depth have less impact on structures than debris.

Timber framed buildings and mobile homes may cause particularly significant loss of life or hazardous rescues in floods (HR Wallingford, 2003). Four people were crushed by their mobile homes and another died in South Carolina, USA, when her mobile home was struck by the storm surge caused by Hurricane Hugo (MMWR, 1989). Single storey buildings, ground floor or basement apartments, car parks and metro systems are especially at risk, not only from flash floods but also from burst mains and sewer flooding. Additionally, people trapped in buildings or on roofs may die from exposure as was the case in the 2000 Mozambique floods (HR Wallingford, 2003), although this is less likely in European flood events due to speedier search and rescue operations.

Significant loss of life can also occur in floods where people cannot find refuge inside or where buildings collapse or are swept away (Green, Parker and Emery, 1983; cited in HR Wallingford, 2003); in the 1991 Bangladesh cyclone 138,000 people died. A survey of 45 housing clusters comprising 1123 people showed that nearly 22% of people that failed to reach a concrete or brick structure died whilst everyone who sought refuge in such structures survived (Bern *et al.*, 1993). Problems are also exacerbated by the fact that in many countries, floodplains are the only available space for settlements particularly by poor and migrant people who in addition to settling in these more vulnerable areas usually lack the resources to build robust structures (HR Wallingford, 2003).

Deaths can happen inside buildings when the water levels rise very quickly and people are trapped in lower levels or are unable to reach higher floors; eventually the floodwaters can exceed the highest floor of a property. Most of the fatalities in Romania during the August 2005 floods drowned as floodwaters rushed into their homes (CBS News, August 25, 2005).

Deaths by fire, electrocution and carbon monoxide poisoning have also been reported as an indirect consequence of flooding, often during the clean up phase (e.g. MMRW, 2005; MMRW, 2000; MMRW, 1989) and these deaths generally occur inside buildings (Jonkman and Kelman, 2005). Two men died when overcome by carbon monoxide fumes from a generator being used to pump floodwaters from a cellar following the July 2007 floods in England (BBC News Website, 2007). Jonkman and Kelman (2005) found in their study of 13 flood events in Europe and the US that all the deaths due to electrocution or fire occurred in the US. However, this may be due to the way the deaths were reported or that most US events were associated with cyclones whereas the European ones were mostly river floods.

2.3.4 Population characteristics

There are some characteristics of a population which can worsen the consequences of a given flood. Research by RPA, FHRC *et al*. (2004) has shown that the very old (over 75s), single parents and the long-term sick can be more vulnerable to the effects of a flood. Financial deprivation will also increase vulnerability.

One method for assessing the vulnerability of populations to flood impacts is the Social Flood Vulnerability Index (SFVI) (see Tapsell *et al*., 2002). The SFVI was originally developed for the Catchment Flood Management Plans in England and Wales, for the development of a modelling and decision support framework (Defra/Environment Agency, 2002). It is a composite additive index based on three social groups (the elderly aged 75 and over, single parents, and the long-term sick) and four financial deprivation indicators (unemployment, overcrowding in households, non-car ownership, and non-home ownership). The rationale for the selection of these variables to predict increased vulnerability to flooding is given in Table 2.2.

Table 2.2: Variables in the Social Vulnerability Index

Variable	Rationale
Very old (75 or over)	Epidemiological studies show that after this age there is an increase in the incidence of arthritis and other conditions that can be exacerbated by the conditions associated with a flood.
Lone parents	FHRC research has shown that lone parents are more vulnerable to the effects of a flood because they have lower income and have to cope with both their children and the effects of the flood on their own.
Pre-existing health problems	Research by FHRC has shown that flood morbidity and mortality is significantly higher for those victims that suffer from previous health problems.
Financial deprivation	The financially deprived are less likely to have their home contents insured and therefore have more difficulty and take longer to replace the items damaged by a flood.

Source: Tapsell *et al.* (2002, p95)

To identify the financially deprived, the Townsend Index (Townsend *et al.*, 1988) was used because, unlike other deprivation indices, it focuses on deprivation outcomes (such as unemployment), rather than targeting predefined social groups. This enabled identification of social classification and is important because financial deprivation is only one of several factors that are said to contribute towards vulnerability to flood-effects, and it was the intention to target only those social groups which previous research has shown to be particularly vulnerable. The Townsend indicators are:

- Unemployment – unemployed residents aged 16 and over as a percentage of all economically active residents aged over 16
- Overcrowding – households with more than one person per room as a percentage of all households
- Non car ownership – households with no car as a percentage of all households
- Non home ownership – households not owning their own home as a percentage of all households.

Other population characteristics that may affect the consequences of a flood may include the number of children in households, the presence of ethnic minorities or those with language constraints, or the presence of people with physical disabilities or learning difficulties. However, only the presence of very old or long-term sick is likely to have an influence on the numbers of deaths and injuries that occur as a direct consequence of a flood event. The other variables are more likely to affect long term physical and psychological health (HR Wallingford, 2003; Tapsell and Tunstall, 2007). The presence of tourists and people that have no previous knowledge of an area is another factor likely to increase a population’s vulnerability as evidenced during the 2002 floods in the Gard region of southern France (Lutoff and Ruin, 2007; Ruin, 2007).

2.3.5 Population behaviour

There is evidence that a number of the deaths that result from flooding can be attributed to the specific behaviours of those in the flood risk area. For example, people attempting to walk or swim in flood waters can be swept away, the danger of this being higher in fast flowing waters (Jonkman, 2003).

Many flood-related deaths occur when people attempt to drive in floodwaters. HR Wallingford (2003) argue that 0.3m of water is sufficient to cause instability to small, light or low motor vehicles while emergency vehicles may resist waters of up to 1 m in depth (HR Wallingford 2005a); safe evacuation by higher and larger vehicles is only possible up to the depth of 0.4m. The FEMA website (2006) warns that "two feet of rushing water can carry away most vehicles including sport utility vehicles (SUV's) and pick-ups". Once vehicles are floating the pressure of the water will prevent the doors from being opened (Jonkman, 2003). In the US, where the National Weather Service has documented flood fatalities since 1903, more than half of all flood fatalities are vehicle related (See http://www.nws.noaa.gov/oh/hic/flood_stats/recent_individual_deaths.shtml). In 2003, five people died in a local flash flood in Poland by drowning in a car (Kundzewicz and Kundzewicz, 2005). However, this problem seems to be worse in the US (Jonkman and Kelman, 2005) where many more people refuse to abandon their vehicles during a flood (MMWR, 1994) than in Europe. In the UK summer 2007 event, two men (both 68 years old) died in separate car-related incidents. Both had driven into flooded areas and were then swept away by the flood waters (BBC Website, 2007a, BBC Website, 2007b). However, the way deaths are reported in Continental Europe may be part of the explanation. According to Kelman (2004) when people drown in a car the deaths are often considered to be traffic deaths.

As well as the chance of being trapped in a vehicle and being swept away by the floodwaters while still within a vehicle, drivers and their passengers will also be directly exposed to flood waters if they are forced to abandon their cars. In addition to the possibility of their vehicle stalling, floating and/or being swept away, travelling on flooded roads will also make motorists susceptible to other flood-related impacts such as damages to roads, bridge collapses or being hit by debris or even other cars being carried by the floodwaters.

Some experimental studies have been conducted to calculate the flow characteristics of a flood (i.e. the product of velocity and depth) that causes humans to lose stability when trying to walk through floodwaters. In a study by Karvonen *et al.* (2000), the product of depth times velocity causing loss of stability varied from 0.64 to 1.26, with taller and heavier individuals managing better in flowing water. Abt *et al*. (1989) reported that a product of 1.0 is the safe limit. Similar results have been obtained in Australia (Emergency Management Australia, 1999; New South Wales Government, 1986). However, more recent research by Penning-Rowsell *et al.* (2003) reproducing circumstances closely resembling urban flash flooding showed that low depth/high velocity floods are much more dangerous than suggested by Abt *et al.* and other studies.

People sometimes underestimate the danger of flood waters and lack imagination about what can happen. People may often underestimate the depth of waters or become disoriented and drift into deeper waters, thus being swept away. Data from the 1997 floods in Poland, cited by Kundzewicz and Kundzewicz (2005), shows that some of the victims died by taking a risk, either consciously or unconsciously. For instance, several cases (all male) were recorded as 'fell into a river and drowned', possibly after attempting to swim and being hit by debris. Other victims died trying to save a dog or collect their belongings and some just wanted to watch or possibly photograph the flood waters. 'Flood tourism' has been reported in several recent European floods, including large groups of people gathering on river banks and pursuing recreational boating on flooded streams (Jonkman and Kelman, 2005; Wilson, 2006) which is a particularly dangerous activity during a flood as small boats can easily capsize in fast flowing water (Jonkman, 2003). Many of these people underestimate the dangers that they may be exposing themselves to.

A review of flood fatalities in Australia between 1788 and 1996 showed that males outnumber female fatalities by 4:1. Most of the deaths (38.5%) occurred when people attempted to cross river channels, bridges or roads during a flood. Moreover, 31.5% of the victims died inside buildings while awaiting rescue or while unaware of the flood (Coates, 1999).

However, exact information on the direct causes of flood-related deaths is generally scarce. Kundzewicz and Kundzewicz (2005) cite the data assembled by Polish journalists on the summer floods of 1997 in Poland which caused a death toll of 50. The data contains the age, gender and details of the cause of death where available. Although it is believed that vulnerability to flooding is higher among the elderly, those with prior health problems and those with small children, the information collected by these journalists shows that some of the deaths were a result of underestimating the risks of a flood.

Risky behaviour is often caused by lack of knowledge of what is best to do in a flood situation. One of the main difficulties of flood management lies in educating the public to react in an appropriate way before or during a flood (WHO-Europe, 2002b). For instance, 95% of flash flood victims try to outrun the waters along their path rather than climb rocks or go uphill to higher grounds (Facts about flooding, no date, http://www.weather.com/safeside/flood/facts.html). Many people in London, when asked what they would do in the event of a flood, said that they would descend into the underground railway system to escape (WHO- Europe, 2002b), which is unwise as the underground tunnels are at risk from flooding and there is high potential for loss of life.

2.3.6 Examples of common flood scenarios in Europe

The combination of flood event, area characteristics including type of dwelling and people vulnerability and behaviour produce different potential scenarios and risk to life. The most frequent types of flood event in Europe are flash floods and riverine floods (Jonkman, 2005). Flash floods have the highest mortality and usually affect smaller areas. River floods affect larger areas and consequently more people but generally cause lower mortality. A review of 220 flood events in Europe recorded by the OFDA/CRED International Disaster Database showed that the average mortality (number of fatalities/total affected) for flash flood events is 5.6% of affected populations compared to 0.47% for river floods (Jonkman, 2005).

Flash floods are frequently caused by heavy rain in hilly or mountainous areas. Table 2.3 shows the examples of different flash floods that affect Europe and the Mediterranean. Flash floods are frequent in southern Europe and loss of life in those events is common (Lutoff and Ruin, 2007). For instance, the south of France has suffered flash floods almost every year since the 1990s: 46 people died in 1992, 10 in 1993, four in 1996, 29 in 1999, 21 in 2002 and 5 in 2003 (Guardian, December 4, 2003). In the 2002 flash floods in Provence, six months' rain fell on the area near Nimes turning a '*tiny stream into a 300 m wide torrent*' (Guardian, September 11, 2002). Flash floods allow no warning or just a short warning, which increases area vulnerability, as it affects the position of people within the floodplain. Thus, many motorists were trapped in the flood and other victims were trapped outdoors (a father and his two children aged 2 and 6 died after taking refuge in a tree and being swept away). Several people also drowned in their homes (Guardian, September 11, 2002). Types of land use and development within floodplains can affect the characteristics of a flood. The south of France is a popular area for French second homeowners, and people from the UK, Germany and other central European countries choose the area for their retirement. Many new homes have been built in low lying areas, thus also reducing the natural infiltration of the ground. Moreover, intensive agricultural practices have compacted the soil and accelerated run-off by growing crops on hillsides (Guardian, December 4, 2003).

Flash floods are not only associated with steep terrain but also with the flooding of flat areas where the slope is too small to allow the run-off of floodwaters. The water accumulates on the surface or in low-lying areas such as underground car parks or basements (Kron, 2002). During the June 2007 floods in Hull, UK, intense rainfall resulted in the urban drainage systems being overwhelmed thus flooding thousands of properties (Coultard *et al.*, 2007; Crichton, *et al.*, 2007).

Table 2.3: Examples of flash flood scenarios which have occurred in Europe and the Mediterranean region

Flash flood type	**Areas generally at risk**	**Examples**
Flash floods caused by heavy rainfall in hilly or mountainous areas	Mountainous and hilly areas (Alps, Apennines, Pyrenees,etc.)	Las Nieves campsite, Biescas, Spain (7 Aug 1996: 87 deaths) Tenerife, Spain (1 Apr 2002: 6 deaths) Bab El Oued, Algiers, Algeria (9-10 Oct 2001: over 300 deaths)
Flash floods caused by snowmelt and rainfall in mountainous areas	Mountainous and hilly areas (Alps, Apennines, Pyrenees, etc.)	North West Romania (3-6 Mar 2001: 0 deaths)
Flash floods caused by heavy rainfall in arid and semi-arid areas (wadis)	Southern Europe	Soverato, Italy (9-10 Sep 2000: 28 deaths)
Flash floods caused by rainfall on saturated ground (permeable catchments)	Areas on permeable catchments (e.g Chalk, Limestone, etc.)	Chichester, UK (Jan 1994: 0 deaths)
Flash floods linked to reservoir outbreak or overtopping:		
i) landslide-driven	Across Europe	Vajont Dam, Italy (9 Nov 1963: 1909 deaths)
ii) lahars (linked with volcanoes)	No known recent occurrence in Europe	
iii) jokulhaups (linked to volcanic activity)	Iceland	Bardarbunga mountain, Vatnajokull Glacier, Iceland (4 Nov 1996: 0 deaths)
iv) river or lake outbursts (ice dams)	Northern Europe	Ice dams often are formed in winter on rivers and lakes in Scandinavia and Iceland
v) man-made dam breaks	Across Europe	Malpasset Dam, France (1959: 433 deaths) Stava Dam, Italy (July 1985: 268 deaths)

Source: Adapted from Colombo, Hervás and Vetere Arellano (2002a, p63).

Campsites are particularly vulnerable areas as tents and caravans may not provide safe refuge in the event of heavy rainfall or a flash flood. People vulnerability in campsites may also be high due to the presence of families with children and also of people that do not necessarily know the area. Tourists are thus particularly vulnerable to flash floods (Lutoff and Ruin, 2007). An example is Biescas, Spain where in 1996 86 people died as a consequence of the floodwaters and mud that covered a campsite during a flash flood (WHO-Europe, 2002a).

River flooding has been recently recognised as a major hazard in Central Europe (Kundzewicz *et al.*, 2005). Slow rising floods affect larger areas than flash floods and usually provide longer lead times for warnings. Substantial riverine floods occurred in Central Europe in 1993, 1995 and 1997 (Rosenthal and Bezuyen, 2000) and more recently in 2002 and 2005. In 1997, long periods of rainfall caused floods on the Vistula, Oder and Niesse rivers. There were over 100 fatalities in Poland and the Czech Republic (Rosenthal and Bezuyen, 2000). The 2002 Central European floods caused over 100 fatalities across Europe. They were triggered by two rain-bearing meteorological depressions that crossed Europe in close succession during August 2002. The first storm formed in the Atlantic on July the 31st and crossed across northern England and Scotland, causing minor flooding. By the 6th and 8th of August, the storm had reached southern Germany and Austria resulting in torrential rain. This storm was rapidly followed by another depression that caused heavy rain in Italy, before moving to Austria, Czech Republic and southern parts of Germany. The rainfall continued in Central Europe until the 14th of August. Flooding occurred in the catchments of the Moldau, Mulde, Elbe and Donau. The nature of this flood event allowed flood warnings to be issued and emergency operations were undertaken in all affected countries to improve flood defences and evacuate areas at risk (Toothill, no date).

The above mentioned 1997 and 2002 floods and the 2001 Vistula (and its tributaries) flood have several common characteristics: they took place in summer and were generated by intensive rainfall during a longer wet spell that covered vast areas. As well as slow rising floods in the main rivers, these events also caused violent flash floods in the smaller catchments. Huge masses of water caused dyke breaches and inundation of large urban areas. The dyke breaches and consequent inundation of agricultural land provided a relief to downstream areas. These floods ranged from very rare events in the headwaters to more frequent return periods downstream (Kundzewicz *et al.*, 2005).

The combination of snow melt and rainfall is another common cause of flooding in winter and spring. This type of flood is typical of Central Europe (Colombo and Vetere Arellano, 2002) and Italy (Guzzetti *et al.*, 2005).

2.4 Examples of 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; Jonkman *et al.* (2002) reviewed several methods to calculate loss of life. The number of fatalities caused in a flood depends on a large number of characteristics (as discussed above), however, most of the models reviewed by Jonkman *et al.* (2002) limit themselves by only taking into account some of these characteristics when modelling loss of life.

Waarts (1992; cited in Jonkman *et al.*, 2002) bases his model on just one flood event - the 1953 Netherlands flood which caused 1800 deaths, which limits its applicability to other events, and suggests two relationships between water depth and loss of life:

$$\delta_{h1} = 0.665.10^{-3}.e^{1.16.h}$$
$$\delta_{h2} = 0.4.10^{-3}.e^{1.27.h}$$

where

δ_{hi} = fraction of inhabitants of the area drowned (i= 1,2)
h = water depths (metres)

The mortality curve rises quickly above 5 metres, when most houses will be completely flooded (Jonkman *et al.*, 2002).

Another model based on the 1953 flood event was developed by Vrounwenvelder and Steenhuis, 1997 (cited by Jonkman *et al.*, 2002). This model takes into account death by building collapse and other causes. The model gives different equations for houses that are washed away near dyke breaches, houses that collapse due to wave attack and a third equation for other causes of loss of life. This model also takes into account an evacuation factor when summing up the results of the three causes:

$$N = (F_O + P_BF_R + P_SF_B)(1-F_E)N_{PAR}$$

Where:
N = total fatalities
F_O = fatalities due to other factors
P_B = probability of dike breach
F_R = fraction of fatalities near the breach
P_S = probability of storm occurring
F_B = fraction of buildings collapsed
F_E = fraction of people evacuated
N_{PAR} = population

Based on Waarts' formula, Jonkman (2001; cited in Jonkman *et al.*, 2002) proposes another method to estimate loss of life in the Netherlands, which also incorporates Abt's (1989) work on human stability. This model additionally includes the evacuation factor based on the time available for evacuation. In

Jonkman's formula, evacuation time, depth and velocity are a function of the location in the floodplain.

Brown and Graham (1988) used a function based on the size of the population at risk and time available for evacuation and presented a simple algorithm for estimating loss of life due to dam failure:

$N = 0.5N_{PAR}$ when $T_A < 0.25$ hr
$N = N_{PAR}^{0.6}$ when $T_A > 0.25$ hr and < 1.5 hr
$N = 0.0002N_{PAR}$ when $T_A > 1.5$ hr

Where:
N = fatalities
N_{PAR} = at-risk population
T_A = time available for evacuation

As Jonkman (2005) points out, this model is extremely sensitive to the T_A function and also assumes that the time available for evacuation is equal to flood warning lead times. This assumption is questionable since there are often delays in warning response.

Graham (1999) provided a framework for estimating the numbers of fatalities and injuries due to dam failures as a function of the flood severity, warning lead-times, the number of people occupying the at-risk area, and the population's understanding of flood severity. Based on these parameters, different fatality rates, derived from a database of 40 historical dam breaks, are applied to the at-risk population. As Table 2.4 illustrates, as well as a single mortality factor, there is a suggested range of fatalities.

Table 2.4: Mortality factors for medium and low flood severities

Flood severity	Warning Time (minutes)	Flood severity understanding	Fatality Rate (Fraction of people at risk expected to die)	
			Suggested	Suggested range
Medium	No warning	N/A	0.15	0.03 – 0.35
	15 to 60	Vague	0.04	0.01 – 0.08
		Precise	0.02	0.0005 – 0.04
	More than 60	Vague	0.03	0.0005 – 0.06
		Precise	0.01	0.002 – 0.02
Low	No warning	N/A	0.01	0.0 – 0.02
	15 to 60	Vague	0.007	0.0 – 0.015
		Precise	0.002	0.0 – 0.004
	More than 60	Vague	0.0003	0.0 – 0.0006
		Precise	0.0002	0.0 – 0.0004

Source: Graham (1999, p34).

Unlike the Brown and Graham model, this method attempts to take into account the response time to flood warnings by including the 'flood severity understanding' parameter.

According to Jonkman (2003) flood-mortality functions should be preferably based on reliable data derived from historical floods. However, the availability of extensive quantitative data from historical floods is in general very limited. Jonkman (2003) developed a simple 'flood-mortality function' based on the 1953 flood in the Netherlands which caused 1836 deaths. In this function, the probability of drowning is statistically related to the hydraulic characteristics of the flood, such as water depth, velocity and rate of rise.

Based on data collected from the 1953 floods, Jonkman (2003, p.7) relates mortality (i.e. percentage of population in an area that lose their life in the flood) to flood characteristics and distinguishes between three causes of death:

- Drowning due to rapidly rising water
- Drowning due to high flow velocities
- Deaths due to other causes (e.g. hypothermia, heart attack, shock, failed rescue)

Zhai *et al*. (2006) based their model on a database of 269 historical flood events that occurred in Japan during the period 1947 – 2001. The database contains information on loss of life and injury, and also records the numbers of residential properties that were flooded and, of these, the numbers that were damaged or destroyed. The authors propose that the number of flooded residences is an indicator of:

- flood severity
- size of the at-risk population
- number of flood-related injuries/fatalities

They propose the simple formula:

L = S(H)

Where:
L = number of injuries/fatalities
H = number of flooded buildings
S = mortality function derived from the database

The probability of injury or death per event (societal risk, R) can be estimated by dividing the equation by the total population:

$$R = \frac{L}{P} = \frac{S(H)}{nH}$$

P = total population
n = number of residents per building

The authors carry out regression analysis on the numbers of flooded buildings and the number of injuries and fatalities and, from this, identify a threshold of 1,000 buildings, beyond which the number of fatalities and injuries increases with the number of inundated buildings. For events that exceed this threshold, they suggest the formula:

$$\log_{10} L = \alpha \log_{10} H - \beta$$

Where the mortality function (S) is replaced by the slope and intercept of the regression model. The societal risk is then expressed as:

$$R = \frac{H^{\alpha-1}}{n10^{\beta}}$$

An interesting feature of this research is that when the historical data was analysed at decadal intervals, the authors found that the fatality/injury coefficients decreased with time. They suggest that this is, at least in part, because of improved institutional arrangements such as flood warnings and emergency response. These last factors are discussed in more detail in later Sections.

According to Jonkman (2003), the relationships between flood characteristics and deaths, and knowledge about evacuation times, need to be integrated within a 'loss of life' model, preferably developed within a Geographic Information System (GIS). The overall framework of Jonkman's loss of life model uses information about the number of people living in the area, the capacity of the available infrastructure and the time of inundation to estimate the number of people unable to evacuate. This is combined with the information on water depth and velocities used in the flood mortality function and the outcome is a GIS map showing the predicted number of fatalities at different locations in the flooded area.

Jonkman (2007) later refined his earlier analyses to propose a method of estimating fatalities in large-scale floods that occur in low-lying areas due to flood defence failure. These are conditions that tend to occur in deltaic regions, such as the Netherlands. The Jonkman model was developed using a database of eleven historical flood events, with a total of 165 separate locations. The method includes:

- Flood depth
- Flood water velocity
- Rate of rise (speed of onset)
- Arrival time of flood waters at a location following a breach

The model parameters are combined with a dose-response function to produce a mortality fraction (F_D) which is then applied to the exposed population. The mortality fraction varies according to the flood characteristics, which in turn are affected by the distance from the site of the defence breach. Three hazard zones are proposed:

- Breach zone – areas immediately adjacent to the defence breach, characterised by high water velocities, leading to building collapse and instability of people.
- Zones with rapidly rising waters – these zones are adjacent to Breach Zones. A suggested definition of 'rapidly rising' is given as a rate of rise greater than 0.5 m/hr. The rapidly rising waters may not allow enough time for people to reach shelter in the form of higher ground or upper storeys of buildings.
- Remaining zone – these areas are peripheral with respect to the breach. Flood conditions are slow-onset, giving more time for people to find shelter

Jonkman also considers evacuation, available shelter, rescue, and escape (self-evacuation) and how these affect the size of the at-risk population. In the model the Breach Zone is defined by the flood characteristics:

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

Where
h = water depth (m)
v = water velocity (m/s)

In these circumstances it is assumed that total destruction of masonry, concrete and brick houses occurs. It is also assumed that most people will stay indoors, and that they will not survive building collapse. The F_D in this case is therefore given as 1 (i.e. all the exposed population in the breach zone will be killed) although Jonkman does concede that this is probably overstating the case.

In zones with rapidly rising waters, the F_D is related to flood depth (h) and is given by the equation:

$$F_D(h) = \phi_N\left(\frac{\ln(h) - \mu_N}{\sigma_N}\right)$$

Where
ϕ_N = cumulative normal distribution
μ_N =average normal distribution
σ_N =standard deviation of normal distribution
These are coefficients derived from the database. In this case the values are:

$$\mu_N = 1.46$$
$$\sigma_N = 0.28$$

These values apply if ($h \geq 2.1$m and $w \geq 0.5$m/hr) and ($hv < 7m^2/s$ or $v < 2$m/s)
Where w = rate of rise

The mortality fraction with respect to the remaining zones is calculated in the same way as for zones with rapidly rising waters although the coefficients are altered to:

$$\mu_N = 7.6$$
$$\sigma_N = 2.75$$

If ($w < 0.5$m/hr or ($w \geq 0.5$/hr and $h < 2.1$m)) and ($hv < 7m^2/s$ or $v < 2$m/s)

As stated above, Jonkman's model is designed for large-scale floods caused by flood defence failure in low-lying areas which are characteristic of deltaic regions. However, flood events in many other parts of Europe are quite different from the situation in the Netherlands, thus Jonkman's model may not be applicable in these different situations.

The models described in the above section involve mortality fractions based on empirical observations, which are then applied to the exposed population according to flood severity and other parameters such as flood warning and/or awareness. 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. The *Risk to People* model for estimating loss of life is fully described in the next Section.

3. The 'Flood risks to people' methodology

The Flood Risks to People Project Phase 1 and 2 developed a methodology for assessing flood risks to people. The project covered deaths or serious harm to people that occur as a direct result of a flood either during or up to one week after the event. The methodology was developed to be applicable to the UK and can be used to assess and map flood risk to people at different scales (for example, flood event, regional or national scale). Phase 1 of the project developed a formula that combined information on flood hazard with criteria related to the vulnerability of areas and people to flooding for estimating the likelihood of serious injury or death from flooding. Phase 1 calibrated the formula using three historical UK flood case studies of Norwich 1912, Lynmouth 1952 and Gowdell 2000 (HR Wallingford, 2003). During Phase 2 (HR Wallingford, 2005a) a number of changes were made to the formula and the model was retested on the case study of the Carlisle flood in 2005. The basic method and the final model developed (henceforth known within this report as the *Risk to People* Model) will be explained below, however readers are advised to refer to the reports generated by the original two projects (HR Wallingford 2003; 2005a) for more detailed information concerning the model's development and case study testing.

As the *Risk to People* model has been to some extent 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. Following the results of this calibration with European flood event data, the plan was to refine the model if necessary to apply to flooding in the rest of Europe.

At this early stage it is pertinent to consider that the model is based upon a series of different criteria and there are obviously many other factors that the model does not consider. This issue is raised again within Section 3.7 when beginning to consider the appropriateness and/or adaptability of the *Risk to People* model to European floods more generally. The model works on the premise that the numbers of deaths can be calculated from a function of those who are within the 'at risk population': that is those who are exposed to the flood hazard.

Three broad sets of characteristics have been used to try to determine the number of fatalities and serious injuries from a flood event. These are indicative of the often held notion that flood risk is a product of the hazard and the vulnerability to a particular event (Raynor and Cantor, 1987; Dracup and Kendall, 1990; Blong, 1997; Lewis, 1999). The characteristics considered within the model are:

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

Based on these characteristics, the following formula (Figure 3.1) was developed to calculate the number of injuries produced by a single flood event. More specifically the *Risk to People* model functions by initially calculating the expected numbers of serious injuries from a flood event and then this figure is used to calculate the expected numbers of deaths from the event. Therefore the model works by estimating the number of fatalities by taking this as a function of the number of those injured.

$$\textbf{Number of Injuries } N(I) = 2N_Z \times \frac{\text{Hazard Rating} \times \text{Area Vulnerability}}{100} \times \text{People Vulnerability}$$

where,

- N(I) = number of injuries
- N_Z = population living in the floodplain
- Hazard Rating = function of the flow characteristics of the flood, i.e. depth (m) and velocity (m/s) and the 'debris factor' (score).
- Area Vulnerability = function of the effectiveness of flood warnings, speed of onset, type of buildings
- People Vulnerability = function of the number of very old people (over 75) and long term sick/ disabled/infirm. This factor is expressed as a percentage

Figure 3.1: Risk to People model flood injuries formula

The number of fatalities from a flood event can then be calculated from the injuries formula as this is considered by the *Risk to People* methodology to be a function of the number of injuries and the hazard rating. Thus, the more severe the flood (in terms of depth, velocity and debris) the higher the proportion of fatalities among the injured. Figure 3.2 illustrates this formula and its components.

$$\textbf{Fatalities} = 2N(I) \times \frac{HR}{100}$$

where,

- N(I) = number of injuries
- Hazard Rating = function of the flow characteristics of the flood, i.e. depth (m) and velocity (m/s) and the 'debris factor' (score).

Figure 3.2: Risk to People model flood fatalities formula

These characteristics are now discussed in more detail in the following sections.

3.1 Flood Hazard Rating (HR)

The flood hazard rating is used in the methodology as a variable that affects the proportion of exposed people which are injured or killed. The degree of hazard that flood waters present to people depends on the velocity and depth and the presence of debris. After considering a number of alternative equations with reference to experimental data, the final formula used to calculate the hazard rating to people shown in Figure 3.3 was:

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

where,

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

Figure 3.3: Risk to People model hazard rating

Experimental work from Abt *et al.* (1989) and the Karvonen *et al.* (2000) was reviewed and the above formula was found reliable for determining the threshold for losing stability in flood conditions. However, it was also acknowledged that there are differences between the two experiments and that they do not reproduce real-life conditions. Therefore, it was recommended to be precautionary in setting and describing hazard classes.

3.2 Area Vulnerability (AV)

The Area Vulnerability determines the number of people exposed to the flood and also provides a consideration about whether they are able to escape the flood waters. At any particular time people may be in a number of locations for instance; outdoors, indoors, inside a vehicle or in a basement. The Area Vulnerability therefore is a function of flood warning, speed of onset and the nature of these areas (Figure 3.4).

Area Vulnerability (AV) = Speed of onset + Nature of the area + Flood warning

Figure 3.4: Risk to People model area vulnerability score

In the methodology, each of the factors received a 1, 2, or 3 score illustrated in Table 3.1.

Table 3.1: Area Vulnerability scores

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[2] P2 = % of Warning Time Target Met[3] P3 = % of Effective Action Target Met[4]		
Area Vulnerability (AV) = sum of scores for 'speed of onset', 'nature of area' and 'flood warning'			

3.3 People vulnerability (PV)

The *Risk to People* methodology examined a number of factors that made people more (or less) vulnerable to flooding or the effects of flooding. These are explained in more detail in HR Wallingford (2005a p16-17). Those illustrated in the formula in Figure 3.5 are those that were considered to be the most important within UK floods. This variable is based on the idea that the very old and the infirm/disabled/long-term sick will be more at risk (young children would also theoretically be more at risk, but they are unlikely to be left alone in a flood).

[2] This is based on the Environment Agency's 80% target
[3] Two-hour warning time
[4] Target: 75% of people taking action

People Vulnerability (PV) = % residents suffering any long-term illness + % aged 75 or over

Figure 3.5: Risk to People model people vulnerability score

Other socio-demographic factors such as income, education, employment status, car ownership and family status will be associated with long term physical and psychological effects but not with direct physical injuries/deaths.

The following formula (Figure 3.6) is used to calculate the numbers of deaths and/or injuries.

N(I) = N x X x Y

where;

N (I) = number of deaths/injuries
N = population within the floodplain
X = the proportion of the population exposed to a risk of death/injury for a given flood (based on the Area Vulnerability)
Y = proportion of those at risk that will suffer death/injury, based on the People Vulnerability

Figure 3.6: Formula for calculating the number of deaths and/or injuries

3.4 Quantifying the risk to people for a single event

With the *Risk to People* model the flood event needs to be properly zoned in order to be able to apply it to single events. This is so that the characteristics and therefore the values assigned to each of the variables are as homogenous as possible over that area. This is particularly important in relation to the hazard rating component as the degree of hazard (depth, velocity and debris) depends on the position of people within the floodplain. How this has been achieved in the UK situation is that the risk zones have been defined as being areas of different distances from the river or the coast (i.e. the source of the water in question). HR Wallingford (2005a, p20-23) present a hypothetical case study to illustrate the application of the *Risk to People* methodology to a flood event. This hypothetical case study (in shortened version) is presented in Figure 3.7. The example has been generated for a 100 year flood (1% probability). It is of course possible however to undertake the same calculation for events of other probabilities. Further examples including those that were used to calibrate the *Risk to People* methodology can be found in HR Wallingford (2005a, p25-35).

Hazard zones, Hazard Rating and Area Vulnerability

Distance from river/ coast	N_Z Population in risk zone	Typical depth d (m)	Typical velocity v (m/s)	Debris factor (DF)	**Hazard Rating** = d (v+0.5) + DF	Flood warning (FW)	Speed of onset (ONSET)	Nature of area (AREA)	**AV = FW + ONSET +AREA**
0-50	25	3	2	1-possible	8.5	2.15	3	2	7.15
50-100	50	2	1.8+	1-possible	5.6	2.15	2	1	5.15
100-250	300	1	1.3	1-possible	2.8	2.15	2	3	7.15
250-500	1000	0.5	1.2	1-possible	1.85	2.15	1	2	5.15
500-1000	2500	0	0	0-unlikely	0	2.15	1	2	5.15

Determining the number of people exposed

Distance from river/ coast	N_Z	Hazard Rating (HR)	Area Vulnerability (AV)	X = HR x AV	$\mathbf{N_{ZE}}$
0-50	25	8.5	7.15	61%	15
50-100	50	5.6	5.15	29%	14
100-250	300	2.8	7.15	20%	60
250-500	1000	1.85	5.15	10%	95
500-1000	2500	0	5.15	0%	0

The area vulnerability score is then multiplied by the hazard rating to obtain X or percentage of people exposed. The number of people affected (N_{ZE}) is obtained by multiplying the percentage of people exposed (X) by the number of people in the area (N_Z).

Calculating the People Vulnerability

Distance from river/ coast	Factor 1 = % of very old	Factor 2 = % disabled/ infirm	Y (**People vulnerability**) = 1 + 2
0-50	15%	10%	25%
50-100	10%	14%	24%
100-250	12%	10%	22%
250-500	10%	15%	25%
500-1000	15%	20%	35%

In order to determine the numbers of deaths/injuries, the number of people exposed (N_{ZE}) is multiplied by a factor Y based on the People Vulnerability. Y is a function of the percentage of over 75s and the percentage of long-term ill.

Determining the number of deaths/injuries

Distance from river/ coast	N_{ZE}	Y = 1 + 2	Number of injuries = 2 x Y x N_{ZE}	Fatality rate = 2 x HR	Number of deaths
0-50	15	25%	8	17%	1
50-100	14	24%	7	11%	1
100-250	60	22%	26	6%	1
250-500	95	25%	48	4%	2
500-1000	0	35%	0	0%	0
All	184		**89**		**5**

The number of injuries is obtained by multiplying the people at risk (N_{ZE}, see Table 6.6.2) by their vulnerability. The number of deaths is a function of the HR and is calculated by multiplying it by 2. In this example, the estimated number of deaths is 5 and the injuries 89:

Figure 3.7: Example of the application of the Risk to People methodology Example figures taken from HR Wallingford (2005a, p25-35).

3.5 Risk to People mapping

A further output of the *Risk to People* project was a mapping component whereby a Geographical Information System (GIS) was used to analyse, manage and communicate flood risks to people. This section describes the approach for mapping flood risks to people as reported in the *Risks to People* project (HR Wallingford, 2005a). The procedure is illustrated in Figure 3.8

There are two elements to be considered in the mapping of flood risks to people:

- A Flood Hazard map, which represents the hazard rating component of the Risks to People methodology and describes the hydraulic conditions affecting the at-risk population.
- A Flood Vulnerability map, which combines the Area Vulnerability and Population Vulnerability components of the methodology and describes the vulnerability of both the area, in terms of e.g. flood warnings and land use, and the population, in terms of age and health status.

The *Risks to People* map finally combines these to describe the individual risk of serious harm due to flooding.

3.5.1 Further Guidance – Flood Hazard Mapping

The Flood Hazard map requires data on flood depth, flood velocity, and a debris factor. There is a range of hydraulic models that can be used to estimate depth and velocity; these may be 1-D models such as ISIS and MIKE11 or 2-D models such as TuFLOW. Alternatively, depths and velocities can be estimated using existing data and expert judgement. Where hydraulic models are used, the model output grids can be digitised or otherwise derived using GIS processing techniques. Figure 3.9 shows the Hazard Rating for Thamesmead (London, UK) which was extracted from the raster output of a hydraulic model. The debris factor can then be added to calculate the Hazard Rating (HR) for each flood cell. Guidance on debris factors according to flood depths and dominant land cover is given in Figure 3.8.

3.5.2 Further Guidance – Flood Vulnerability Mapping

Speed of onset describes the speed at which floodwaters rise. It is determined by catchment and land use characteristics and the nature of flood defences. The suggested values for different risk levels are as follows:

- Low risk. Very gradual onset of many hours. Allows time for warning dissemination and response
- Medium risk. Gradual onset greater than one hour. Allows less time for warnings to be received and acted on
- High risk. Rapid onset of less than one hour. Allows very little or no time for warning dissemination and response

The *Flood warning* score describes the quality of the formal flood warning system in use. HR Wallingford (2005) give suggestions based on the Environment Agency’s performance indicators. This clearly is of no use in the wider European context unless there is equivalent information available in the relevant country. As a brief guide, the Environment Agency’s performance indicators cover three targets: warning coverage, warning time, and effective action taken.

1) Define the spatial extent of the study. The spatial scale will affect the type of data to be used and the level of risk to be assessed.

2) Decide on the severity (return period/annual probability) of the design flood event or events. The UK guidance recommends a minimum of five events and the choice of events is influenced by the presence and quality of flood defences. For areas that are protected by flood defences, more severe events should be modelled compared to undefended areas. For the UK, the recommendations (expressed in terms of the return period) are:

Undefended area with regular flooding – 20, 50, 100, 250, and 1000 year events
Defended area (standard of defence 1:75 years) – 100, 200, 300, 500, and 1000 year events

3) Define flood hazard zones based on hydraulic model outputs and topography or define using existing flood risk maps and expert judgement. For large, low-lying floodplains it may be appropriate to define zones based on distance from the source of flooding.

4) Calculate the Hazard Rating for the flood zones:

$$HR = D * (V+0.5) + DF$$

The debris factor may be seen as optional; the Criteria for Identifying Rapid Response Catchments report (Environment Agency, *forthcoming*) did not apply a debris factor because they considered that there was not sufficient data available to determine an appropriate value. If a debris factor is to be included, Table 1 gives guidance on selecting a debris factor based on land cover and flood characteristics. Otherwise, the debris factor can be omitted from the calculation. Figure 3.9 shows the Flood Hazard zones generated for the Thamesmead area in the UK.

Suggested debris factors for different flood depths, velocities and dominant land cover type

Depths (m)	Pasture/Arable	Woodland	Urban
0 – 0.25	0.0	0.0	0.0
0.25 – 0.75	0.0	0.5	1.0
d> 0.75 and/or v> 2m/s	0.5	1.0	1.0

Further guidance on flood hazard mapping is given above (in Section 3.5.1)

5) For the flood hazard zones identified, use local maps (equivalent to the UK Ordnance Survey maps) and population data to develop an understanding of land use and population characteristics. Also review formal flood warning systems.

Assign scores for speed of onset, land use type, and flood warning quality to the hazard zones to give the area vulnerability score. The area vulnerability score is obtained by assigning values of 1 to 3 to these variables, where 1 represents low risk, and 3 represents high risk. These values are then summed to give the Area Vulnerability score. Because the scoring system is very basic, it is probably not worthwhile devoting a great deal of time and effort to these variables; a broad-brush assessment should suffice. Figure 3.10 shows the Area Vulnerability component of the flood zones identified by the Flood Hazard methodology.

6) Calculate or estimate the percentage of the population that is elderly (e.g. over 65) and the percentage of the population that suffers from long-term illness. The total of these two percentages is the People Vulnerability score.

Note that it may be necessary to divide a flood hazard zone into two or more sub-zones if the land use and/or population characteristics are substantially different within the zone.

Further guidance on flood vulnerability mapping is given in Section 3.5.2

7) Once the flood hazard zones are identified and flood vulnerability within the zones is defined, it is a simple process to calculate the risks to people for each zone. This can be done within a GIS (e.g. ArcView and ArcMap have the necessary functionality) or the data can be exported to a spreadsheet package such as MS Excel. Figure 3.11 shows the *Risk to People* model outputs for Thamesmead in the UK. Note that injuries, not fatalities, are depicted in this figure.

Figure 3.8: Steps for mapping, after HR Wallingford (2005a, p36-48) and HR Wallingford (2005b, p33-46)

Nature of area describes the land use of the flooded area. If the land use is residential, the type of housing is also of relevance.

- Low risk. Areas with few, widely spaced residences, such as agricultural areas. Residential areas where the dominant dwelling type consists of multi-storey flats.
- Medium risk. Commercial/industrial land use types. Residential areas where the dominant dwelling type is two-storey houses.
- High risk. Campsites, single storey schools or other institutions. Residential areas where the dominant dwelling type is bungalows.

As stated above, the Area Vulnerability scoring system is very basic, so it is probably not worthwhile going into too much detail; a broad-brush assessment should suffice. Once the Area Vulnerability component is complete, it should be included in the same file as the People Vulnerability score (step 6, Figure 3.8). Figure 3.10 shows the Area Vulnerability scores for the Thamesmead area (note that People Vulnerability is not shown).

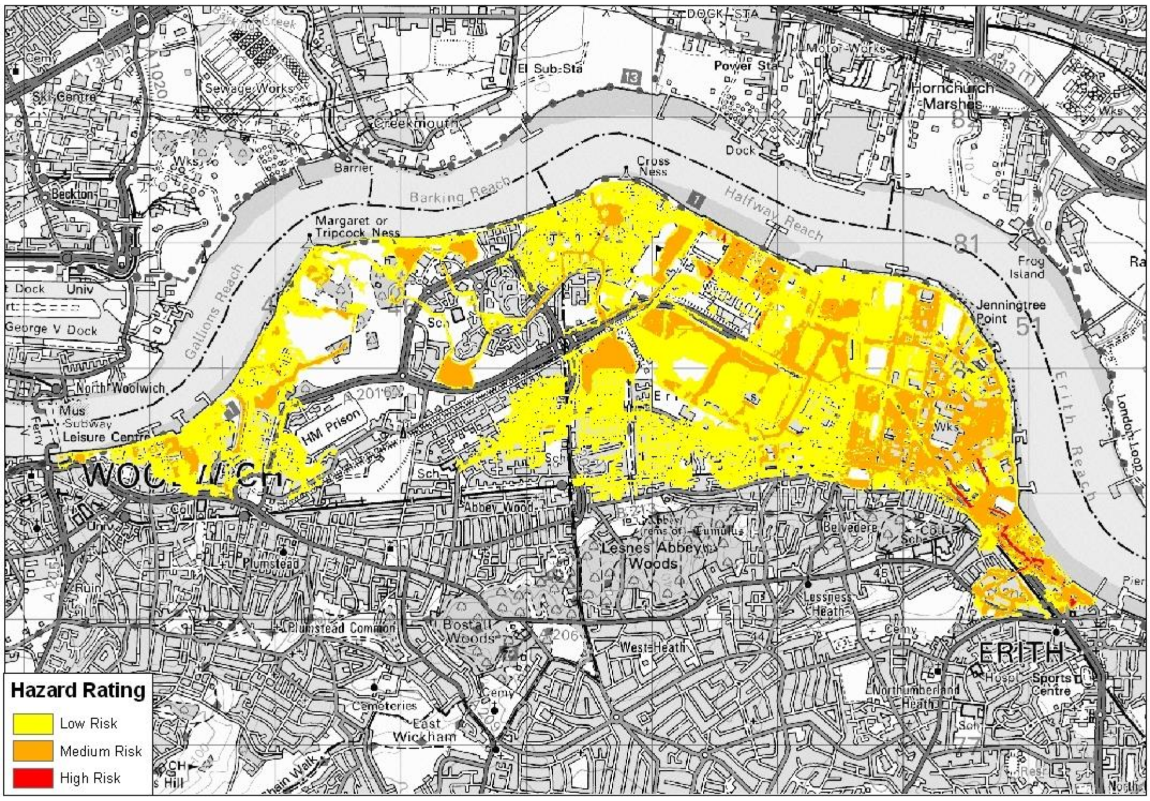


Figure 3.9: Flood Hazard zones generated for Thamesmead (London, UK)

Source: HR Wallingford, 2005a

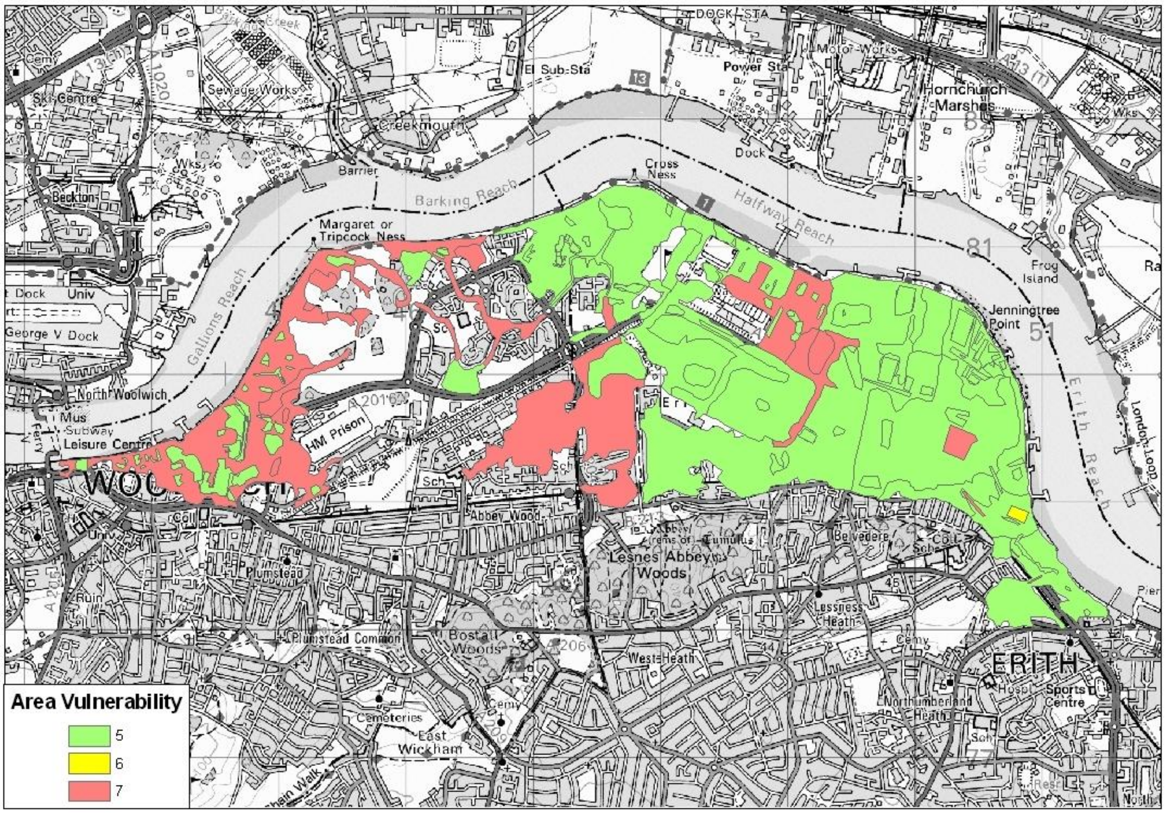


Figure 3.10: Area Vulnerability map for Thamesmead (London, UK)

Source: HR Wallingford, 2005a

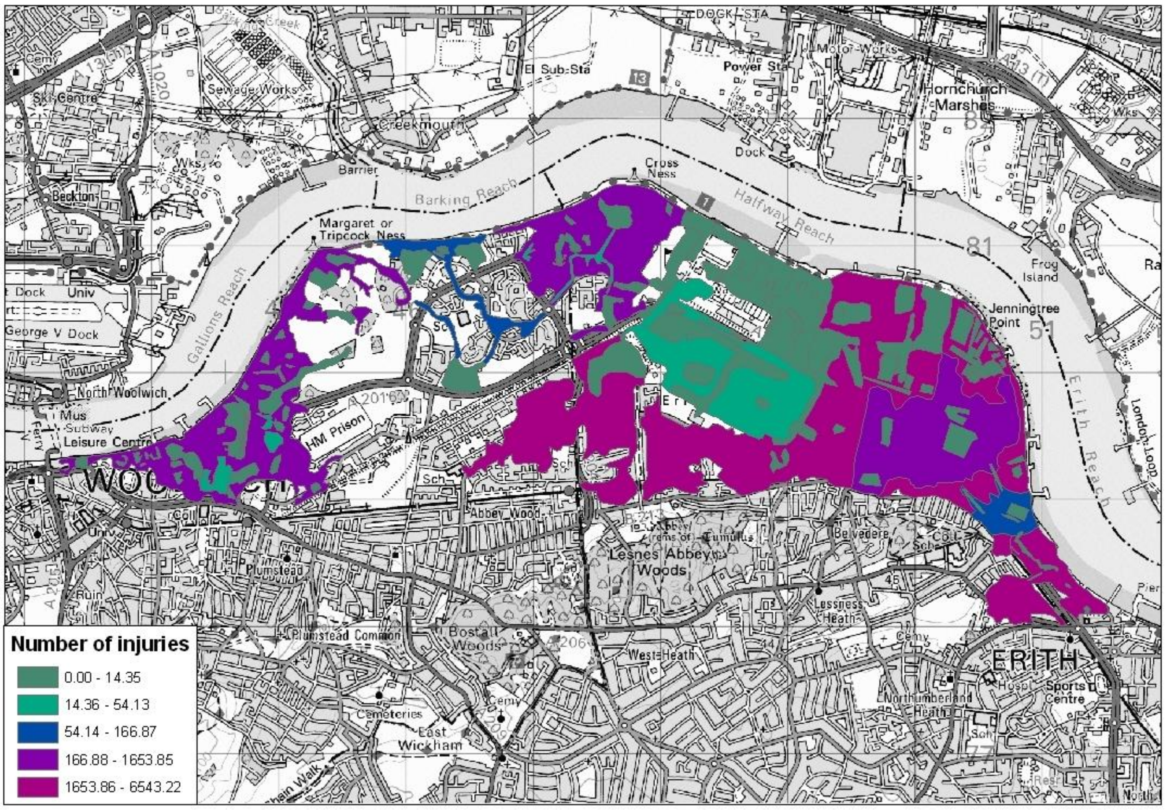


Figure 3.11: Risks to People map for Thamesmead (London, UK)

Source: HR Wallingford, 2005a

3.6 Application of the Risk to People Methodology in the UK

The Environment Agency and HR Wallingford recently applied the Hazard Rating component of the *Risks to People* methodology in Phase 3 of the 'Criteria for identifying rapid response catchments' project (Environment Agency, *forthcoming*). This national scale study focused on catchments where the lag time (the time elapsed between a rainfall event and peak discharge) was estimated to be less than three hours.

The study used an automated GIS approach based on nationally available datasets that was applied to all catchments in England and Wales to provide a rapid, national assessment of potential risk locations. Catchments with a lag time greater than three hours were disregarded since these were outside the scope of the project; catchments smaller than 1 km^2 were also ignored because the authors considered that they were unlikely to be heavily populated. In addition, the method could not be applied to catchments dominated by urban areas since the dynamics of urban flooding is very complex, depending largely on the details of the local drainage system, and the configurations of roads and houses. Moreover, the debris factor was excluded from the Hazard Rating formula because the authors considered that there was not sufficient data available to determine an appropriate value.

Using hydrological and hydraulic algorithms, the study determined the flood depths and velocities for every 250m of river length for each catchment in England and Wales that met the above criteria. The hazard rating was classified as proposed by HR Wallingford (2005c), the classification is summarised in Table 3.2 below:

Table 3.2: Classification applied to the Hazard Rating in the Rapid Response Catchment study

Hazard Rating	Degree of Hazard	Description
<0.75	Low	Caution
0.75 – 1.25	Moderate	Dangerous for some (e.g. children)
1.25 – 2.5	Significant	Dangerous for most people
>2.5	Extreme	Dangerous for all

The method provided a Hazard Rating for every 250m of river length for each catchment. These were classified into four groups of flood hazard degree as shown in Table 3.2. The number and percentage of river sections classified as 'extreme hazard' for each Environment Agency region is shown in Table 3.3.

Table 3.3: River sections identified as 'extreme hazard'

Environment Agency Region	Number of river sections classified as extreme	Total river sections in region	Percentage
North West	15,588	61,339	25.41
North East	17,649	90,174	19.57
Wales	13,343	79,103	16.87
South West	4,681	78,839	5.94
Southern	2,092	42,910	4.87
Midlands	3,147	91,628	3.43
Thames	1,398	52,645	2.65
Anglian	52	114,140	0.05

The study showed that, according to this model, the most hazardous areas occur in mountainous regions. However, the methodology did not take population into account so that, whilst the North West region has the highest percentage of river sections classified as extreme hazard, the region with the highest percentage of population at risk to extreme flash flooding is Wales. As the authors point out, the results of the analysis must be interpreted in a differentiated way. The full report is still awaited.

A further UK application of the *Risk to People* model is discussed in Section 6 in relation to the Boscastle flood of 2004.

3.7 Initial model adaptation of the Risk to People model to the European context

Following a brief investigation concerning the data sources and information that are available in other European countries it was apparent at an early stage that it would be necessary to adapt the *Risk to People* methodology and the model produced if it was going to be possible to use it to estimate the risk to life from Continental European floods. In addition, it was important at the outset to examine and compare the characteristics of European flood events in order to more fully inform the data collection component of this study. This section briefly examines both the initial change to the model and a consideration of additional factors that may be required to assess other types of European flooding.

An initial change was required to the Flood Warning aspect of the Area Vulnerability component of the model due to the fact that the UK appears to hold more information than much of the rest of Europe regarding the reliability, effectiveness and people's response to flood warnings. Therefore, when applying the model to the situation in Europe a much simpler scale has been adopted, although the same numbering of 1 to 3 has been applied. These alternative criteria are shown in Table 3.4.

Table 3.4: Flood warning components applied to the Risk to People model for Continental European case studies

Figure assigned to the model	**1**	**2**	**3**
Explanation	**Good** Where the majority of people at risk received warning with adequate lead time	**Fair** Warning received by some of the population with adequate lead time	**None** No warnings received

Thus, an issue identified that needs consideration in other European flooding relates to the availability of data. It is very problematic even when a flood is well-documented to assign values to many of the *Risk to People* model criteria as many of these would be required to be estimates. Specific issues of this nature will be considered later within this report and many of them are highlighted within the Boscastle case study in Section 6. However, one major issue that needs to be raised at this juncture is the impact of zoning on the results, see Section 4.4. Zoning has of course been attempted where it has been possible, however in a number of circumstances this has not been possible and therefore questions concerning the applicability of the results can be raised.

A further issue relates to the characteristics of floods in Continental Europe which can vary considerably from those that occur in England and Wales. Due to the variations in climate, land use, hydrological conditions and catchment scale (as well as many other variables) many different types of flooding are experienced (Penning-Rowsell and Peerbolte, 1994). In addition to this, the floods in the UK are often considered to be less severe than many of those experienced in Continental Europe, where events are often faster, deeper and more extensive, and therefore can be considered more dangerous to people. Therefore the current methodology does not take into account flood damage to buildings and the risk to people associated with building collapse nor does it consider the 'vehicles factor' highlighted in Section 2.3.5 above (HR Wallingford, 2005a).

Additionally, some areas of Europe experience slow rising flooding which not only permits flood warning but also evacuation. This is a particularly important factor as it may directly affect the population at risk, which has a large impact upon the results of the model. Moreover, the characteristics of many Continental European floods mean that aspects of people's vulnerability come under question. Finally, information about additional factors such as whether there are any language constraints and awareness of flood risk has been gathered. The full set of factors included during data collection is illustrated in Appendix B. The next Section discusses the methodology used in the research for this Task in developing a European Risk to Life model based upon the *Risk to People* model outlined above.

4. Methodology and data collection

4.1 Introduction

A key factor when developing a model such as that proposed in this study is the availability of, and access to, high quality, reliable and detailed data (Jonkman and Kelman, 2005). Without such data the output from any model is likely to be at best crude and at worst extremely inaccurate. A good dataset was therefore vital for the calibration of the current *Risk to People* model, for any revisions to the model, and for successfully achieving the aims of Task 10 Activity 1. The original *Risk to People* model was developed using data from three flood events (Norwich 1912, Lynmouth, 1952 and Gowdell, 2000) (seven flood zones) in the UK and then further tested using five risk zones from the Carlisle 2005 flood event. In order to test the model more widely it was aimed to gather data for a larger number of European flood events. The methodology employed for collecting European data for use in calibrating the model is outlined in the following sections along with limitations and problems arising from the data collection. The Boscastle case study in Section 6 also serves to highlight data collection issues and their impact upon the application of the current *Risk to People* methodology.

4.2 Data collection methods

Following a review of the relevant literature and identification of factors leading to risk to life, a template was produced outlining the relevant data required for the study (see Appendix B). Key flood events in Continental Europe, preferably within the last five years, were identified and similar searches were made on the internet to those outlined in Section 2.1. These searches resulted in little detailed data but were able to provide (largely from media reports and EM-DAT) some information on flood events, numbers of fatalities and people affected by country, date and type of disaster.

In parallel with this, a number FLOOD*site* project partners were contacted in those countries where recent flood events had been identified to have fatalities e.g. Germany, Poland, France, Italy and Spain. Most of these partners were also involved with the Pilot Action case studies in these countries, so therefore potentially had access to available data or would know who to contact to obtain the data. This was thought to be the quickest and most efficient way of obtaining the relevant data. Moreover, as the official language of the FLOOD*site* project is English all partners had high degrees of fluency in the language, which may not have been the case if trying to establish contacts outside of the project.

Those partners identified were therefore sent the data template along with the background information on the aims of the research and guidance on the type of data required for completing the template. When supplying the data partners were also asked to indicate the source of the data along with the quality and levels of uncertainty or accuracy (e.g. sourced from government data, local authorities, residents; if taken from a model, measured or estimated data etc.).

The initial request to partners resulted in the collection of data from various locations and flood events in Italy, Spain and France. Other initial requests for data e.g. Poland and Germany met with no initial success, either because the partners did not have the data, because there had been no deaths in the flood events in their areas, or because partners simply did not have the time to gather the data. However, data from Germany were eventually received on both flash flood and slow rising flood events.

Due to the limited success in obtaining data from FLOOD*site* partners, potential data sources outside the FLOOD*site* project were also sought and contacted e.g. in Poland, Slovenia, the Czech Republic and Romania. In some cases this necessitated translation of information into other languages. Some of these requests for data received no response, despite follow-up emails, and were eventually abandoned. However, successful contacts were made in Poland and the Czech Republic, both of which resulted in good data being obtained as well as very useful background information on the flood events and locations. As this data did not come from FLOOD*site* partners it had to be purchased from the suppliers on a commercial basis.

Initially data was only requested for flood events with fatalities. Towards the end of the data collection period some data were also collected for events with no fatalities. These data were used for comparative purposes when testing calibration of the model. Figure 4.1 maps those locations from which data was received and included for the calibration of the model.

Overall, data were received for flood events between 1997 and 2005. Many of the flood events appear to have the same meteorological cause despite being in different locations and at differing times of the day. In total the data appears to cover 11 different flood events at 25 locations across six European countries, providing 43 different data zones which have 82 deaths. Table 4.1 gives a breakdown of from where the data were collected, the highlighted rows grouping those variables from the same flood event. In the final analysis, not all the flood event data received from all locations were able to be used, for example where data for key variables within the model was not available. Two zones (Botarell and Cagarel) were discarded because some of the key data (e.g. flood depth, population exposed) was missing, six (Stronie Slaskie C, Klodzko Town B, Duszniki Zdroj A, Ladek Zdroj C, Polanica Zdroj B and Dresden B) were not used due to the fact that the population exposed to flooding was zero (since the premise of the model is that deaths are a function of the population exposed) and one zone (Gard) because the data was not able to be disaggregated into different hazard zones. The data from those locations that were not used in the final calibration of the model are indicated in Table 4.1. This leaves 34 usable European datasets which have in total 52 deaths.

4.3 Limitations and problems arising from data collection

4.3.1 Data availability

Limitations in the availability of data have already been outlined in Section 4.2 above. This highlights the need for the establishment of reliable, systematic and consistent methods for collecting data following flood events across Europe, as well as for the need to make available data that is collected. A key constraint concerns who is responsible for collecting such data. In England and Wales the Environment Agency conducts regular post-event surveys and data collection at a national level. However, even here data is not easily accessible and there is no national database of such data. In Federal countries like Germany, where each individual State is responsible for the collection of relevant data, the problem is more complicated and each State would need to be contacted separately to obtain any available data. In other countries national-level data is simply not available.

What had not been anticipated at the outset was the difficulty in obtaining accurate and reliable data. In many cases data on certain variables were simply not available (e.g. numbers of serious injuries, numbers of people evacuated, census data) or it was crudely estimated (e.g. data on flood depths and velocity), often for understandable reasons. In one French example instruments to measure river levels were simply washed away by rising floodwaters, in other examples only the maximum or average depth of flooding was available. In many cases estimates were given, or indeed proxies, and partners were often asked to clarify certain aspects of the data (for example, flood depth and velocity, size and type of debris). Moreover, the majority of data received was for flash flood events and more data on slow rising floods would have been useful.

One problem that had not been foreseen was having to pay for acquiring some of the data. Where data came from commercial sources outside of FLOOD*site* much of it had to be collected specifically for our purposes. These costs were not considerable and were accounted for within the original budget, however, this is an issue that needs to be considered if collecting such data in the future.

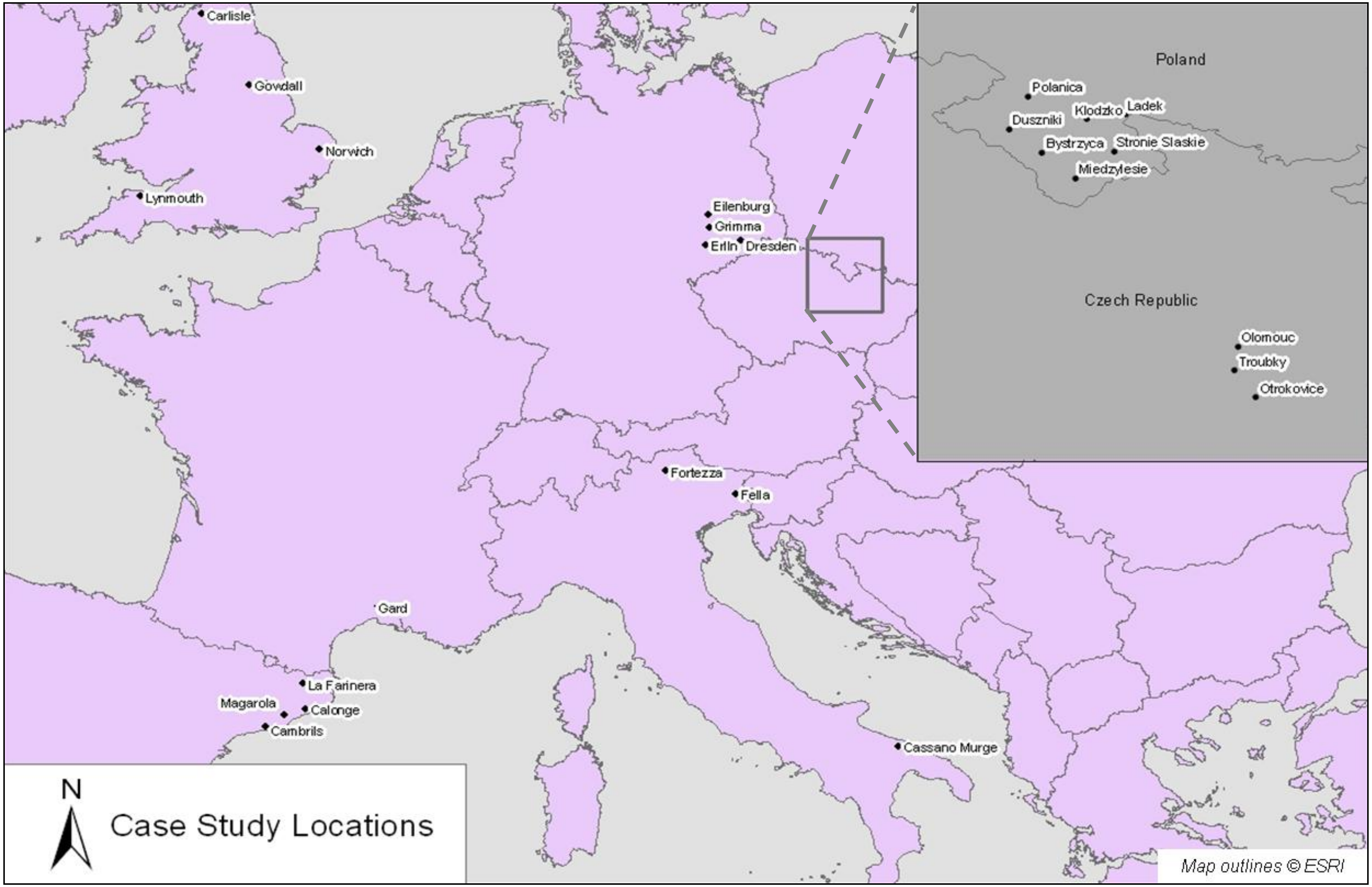


Figure 4.1: Map of locations where flood event data have been gathered

Table 4.1: List of flood event data received (in chronological order)[5]

Date	Location	Country	Flood type	Deaths	Applied In model
6-31 July 1997	Olomouc	Czech Republic	Slow rise (around 3 days before danger situation)	2	Yes
6-11 July 1997	Otrokovice	Czech Republic	Slow rise (around 3 days before danger situation)	1	Yes
6-31 July 1997	Troubky	Czech Republic	Middle risk onset	9	Yes
6/7 July 1997	Stronie Slaskie A	Poland	Flash flood/ Medium risk onset	1	Yes
6/7 July 1997	Stronie Slaskie B	Poland	Flash flood/ Medium risk onset	0	Yes
6/7 July 1997	Stronie Slaskie C	Poland	Flash flood/ Medium risk onset	0	No
7/8 July 1997	Klodzko Town A	Poland	Flash flood/ Medium risk onset	1	Yes
7/8 July 1997	Klodzko Town B	Poland	Flash flood/ Medium risk onset	0	No
7/8 July 1997	Klodzko Town C	Poland	Flash flood/ Medium risk onset	5	Yes
7/8 July 1997	Klodzko Town D	Poland	Flash flood/ Medium risk onset	0	Yes
7/8 July 1997	Klodzko Gmina A	Poland	Flash flood/ Medium risk onset	0	Yes
7/8 July 1997	Klodzko Gmina B	Poland	Flash flood/ Medium risk onset	0	Yes
7/8 July 1997	Klodzko Gmina C	Poland	Flash flood/ Medium risk onset	1	Yes
7 July 1997	Miedzylesie A	Poland	Flash flood/ Medium risk onset	0	Yes
7 July 1997	Miedzylesie B	Poland	Flash flood/ Medium risk onset	1	Yes
7 July 1997	Miedzylesie C	Poland	Flash flood/ Medium risk onset	0	Yes
6/7 July 1997	Bystrzyca Klodzka A	Poland	Flash Flood/ Medium onset	0	Yes
6/7 July 1997	Bystrzyca Klodzka B	Poland	Flash Flood/ Medium onset	0	Yes
7 July 1997	Ladek Zdroj A	Poland	Flash Flood/ Medium onset	0	Yes
7 July 1997	Ladek Zdroj B	Poland	Flash Flood/ Medium onset	0	Yes
7 July 1997	Ladek Zdroj C	Poland	Flash Flood/ Medium onset	0	No
7 July 1997	Ladek Zdroj D	Poland	Flash Flood/ Medium onset	0	Yes
22/23 July 1998	Polanica Zdroj A	Poland	Flash Flood/ Medium onset	0	Yes
22/23 July 1998	Polanica Zdroj B	Poland	Flash Flood/ Medium onset	0	No
22/23 July 1998	Duszniki Zdroj A	Poland	Flash flood/ Medium risk onset	0	No
22/23 July 1998	Duszniki Zdroj B	Poland	Flash flood/ Medium risk onset	0	Yes
22/23 July 1998	Duszniki Zdroj C	Poland	Flash flood/ Medium risk onset	7	Yes
14 August 1998	Fortezza	Italy	Flash flood/High onset	5	Yes
29 August 1998	Fella A	Italy	Flash flood/High onset	1	Yes
29 August 1998	Fella B	Italy	Flash flood/High onset	1	Yes
10th June 2000	La Farinera	Spain	Flash flood/High onset	1	Yes
10th June 2000	Magarola	Spain	Flash flood/Medium risk	4	Yes
22 October 2000	Botarell	Spain	Flash flood/ Medium risk onset	4	No as some data missing
8/9 June 2002	Gard	France	Medium to high risk Flash flooding but the data was not disaggregated	23	No as data was unzoned
12/13 August 2002	Dresden A	Germany	Slow to Medium rise flooding	1	Yes
12/13 August 2002	Dresden B	Germany	Slow to Medium rise flooding	0	No
13 August 2002	Erlln, Mulde	Germany	Slow rise flooding	0	Partly
13 August 2002	Grimma, Mulde	Germany	Slow rise flooding	0	Partly
13 August 2002	Eilenburg – Karl-Marx-Siedlung, Mulde	Germany	Slow rise flooding	0	Partly
7 September 2004	Cambrils	Spain	Flash flood/ Medium risk onset	3	Yes
13th October 2005	Cagarel	Spain	Slow onset (was defined as low risk)	3	No as some data missing
12-15th October 2005	Calonge	Spain	Flash flood/High onset	1	Yes
22 October 2005	Cassano Murge	Italy	Flash flood/High onset	7	Yes

[5] The shading in the table groups zones from the same flood event.

Finally, the length of time taken to gather the necessary data for calibrating the model was in many cases extreme, taking many months from the initial request to receipt of the data. This led to severe delays in making progress with developing the model and the mapping methodology and to the time-schedule for the Task being repeatedly put back. This is another important issue for any future project that needs to collect detailed data from a number of different countries and sources, and important lessons have been learned.

4.3.2 Reliability of data sources

Data supplied by the FLOOD*site* partners and others originated from a wide range of sources, with some of the sources being more reliable and robust than others. In several cases no information was given on data sources. A list of sources is shown in Table 4.2. As previously mentioned the collection and recording of flood-related data is very difficult as the recording protocols and levels of detail available vary considerably between different European countries. Therefore it was often necessary to piece together the data required from different information sources. A further problem encountered (particularly with the reporting of fatalities from flooding) was the fact that different sources contradicted each other (also see Section 5.1). This was especially prevalent when using media reports for information, as the accuracy and completeness of the information depended heavily upon the timing of the report. For instance, people might be reported missing and assumed to be washed away by the flood waters, however when looking at later reporting of the same event, often these missing people would not be mentioned, therefore it was difficult to know whether they had in fact perished or whether they were found safe and well. In cases such as this, only those that were confirmed to have died have been included.

Table 4.2: Sources of data used in calibrating the model

Sources of data
Government departments
National statistics offices
Local authorities (officials and other employees)
Local Land Development Plans
Offical maps and other documents
Academic studies
FLOODsite surveys
Official reports
Fire brigade reports
Eye witness reports
Water level data from monitoring stations
National and local press and media reports
Photographic evidence

4.4 Usability of Continental European data for Risk to People methodology

As mentioned above, the nature of flooding events make them inherently difficult to categorise and collate relevant data. This section explores the relevance of the European data collected for testing the *Risk to People* model and the potential problems associated with these data.

The *Risk to People* methodology appears very sensitive to the zoning of flood events (e.g. that the similar flood characteristics are experienced over the whole zone) and therefore any data that is input into the model is also required to be correctly zoned. This is very difficult as not all the characteristics will be homogenous over the same zones. From the description of the model by HR Wallingford (2005a), and from looking at the makeup of the model, the most important components to ensure that floods are correctly zoned are the hazard rating and the populations that are exposed to flooding. It would be extremely difficult to construct flood zones where each of the different variables within the model was entirely consistent, as this would necessitate the creation of a large number of very small zones for each flood event. As previously mentioned, the measurement and recording of some of these factors during and following flooding is extremely difficult and variable; therefore information at this level of detail just does not exist in many locations. Despite this, those providing this study with data were asked to define different risk zones within the same flood if this were indeed possible and many did manage to achieve this for some of the flood data provided. In one case (Gard, France) it was not possible to disaggregate the data due to the size of the area and population covered, therefore the model could not be applied to this dataset.

Similar to the problems of defining risk zones and the flood characteristics across different areas, estimating both the population at risk from any particular flood event, and subsequently the people vulnerability characteristics (e.g. the percentage of the at risk population over 75 years of age and the percentage of the long-term sick) is equally problematic. In most cases these populations have been estimated from a number of different sources including post-flood reports, the numbers of properties affected and census data. These of course do not include visitors to the area or any other transient populations, and inevitably the census geography will not match the risk zones. Further issues regarding establishing the population at risk are explored in the Boscastle case study in Section 6.2.1.

In addition to the need to ensure that the characteristics that are provided are as homogenous as possible across individual risk zones, a further potential problem with the data provided is that it is a snap-shot of the flooding situation and often does not reflect the changing risks within a single flood event. Therefore there is some doubt concerning which values should be provided for the physical characteristics. In many cases the maximum values have been provided, however this will have only occurred at the peak of the flooding. This is particularly significant in those floods where there was a period of less severe flooding prior to the floodwater's peak which would not only serve as a warning to people, but also in the more severe cases allow them to escape from danger.

The above factors raise questions about both the purpose of modelling risk to life (for instance is it calculating a worst case scenario?) as it is unlikely to be able to forecast accurately the exact number of deaths. Or is it to be used as a guide to the identification of those areas which are most likely to suffer fatalities from flooding? These questions are returned to in the concluding Section.

4.5 Summary

As stated in the introduction to this section, a good dataset is vital for the calibration of the *Risk to People* model and for successfully achieving the aims of Task 10 Activity 1. Without detailed and reliable data the output from any model is likely to be at best crude and at worst extremely inaccurate. It is also likely that any model or methodology generated for Europe will need to recognise this potential shortfall in available, and accurate, flood event data. Despite the many problems experienced in obtaining data for this research, and with the quality of some of the data received, it is nevertheless the best data that is currently available and is likely to be one of the largest datasets used to date to estimate loss of life from flood events in Europe. It was still possible to use the data collected to test the applicability and appropriateness of the *Risk to People* methodology within the European flooding context.

The following Section discusses the circumstances and causes of European flood-related deaths in order to better understand the factors affecting risk to life.

5. Analysis of the circumstances and causes of European flood-related deaths

This Section provides a more in-depth analysis of European flood events and those factors leading to fatalities. It looks at whether these factors are included, or could be included, within the UK model. Those flood events (zones) where no deaths were reported are also analysed to identify possible reasons why no fatalities occurred, and therefore to lead to possible model refinements. The first issue to be discussed is how fatalities are reported.

5.1 Reporting of fatalities

Central to the analysis of fatalities during a flooding event is the quality of data regarding the circumstances surrounding the loss of life. As reported above in Section 4.3.1 there is no systematic system for collecting flood data across Europe and this includes information about deaths. Therefore data on this issue is often difficult to find and the level of detail presented varies enormously. Much of this information needs to be pieced together from a number of sources including official flood reports, media reports and unofficial sources. The reliability of much of this data from whatever source is often also reliant upon eye witness reports, the quality of which may vary greatly, particularly during the often traumatic experience of a flood event. Other official sources which might yield information would be coroners' reports and other medical records. These however, have their own access issues and may not detail specific information about the circumstances leading to injury or death, merely stating cause of death as drowning or heart attack, or a medical explanation of injury.

Coupled with issues relating to the availability of data surrounding known flood deaths, there is also the issue of "missing deaths" or deaths that may have been misattributed to a flood event. Jonkman and Kelman (2005), as outlined in Section 2.2, discuss the problems associated with the indirect deaths associated with flood events. These are often victims who died some days or weeks after the event and often whose death was not reported as being flood related. In these situations the numbers of flood deaths would not reflect the true loss of life from the event. In the other circumstance, although less common, there are instances where deaths have occurred that have been for some other reason than the flood itself (e.g. due to the impact of the storm associated with the rainfall) but the death has been labelled as being part of the natural event and then subsequently attributed as a flood-related death. This is obviously not very useful within any detailed analysis of deaths, as incorrectly attributing deaths to a flood will potentially overestimate the influence of that event. Therefore, it is necessary to be cautious when using information about flood-related fatalities. In addition to the information about the circumstances leading to a flood fatality there is also the issue of the age of the event. The two main calibration events for the UK *Risk to People* model were Lynmouth which was 1952 and Norfolk in 1912. Much has been written about the Lynmouth event and there is much information about cause of death. Information about the 1912 event is much more difficult to find and the validity of the sources more difficult to assess.

The following sections examine in as much detail as possible the deaths that have occurred in both the UK calibration datasets as well as those from the newly collected European data. A general examination of those factors leading to a loss of life is made to identify overall patterns and trends before a more detailed analysis of case study examples. Information in this analysis has been gathered and provided in the partner survey from a range of different sources including official flooding reports prepared by authorities after the events, from professionals involved in flood management and recovery, local authorities, and eye witness reports, see Section 4.3.2. In addition, this information has been supplemented with data gathered from media reports published and broadcast at the time of the event.

5.2 Circumstances leading to death from flooding

Analyses were undertaken to compare and contrast the ways in which people died in the UK events with the factors surrounding death 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. Tables 5.1 and 5.2 illustrate, in as much detail as was available, how the victims died and other personal information; they also include details about the sources of the information.

5.2.1 UK flood-related deaths

As can be seen in Table 5.1 there were a number of different reasons why people died in the UK events, and information from all of the events is adequate to make some conclusions about the causes of death. The Lynmouth case study is the most useful, due to the higher number of fatalities and the level of detail that has been recorded about the circumstances leading to casualties. Although referred to as the Lynmouth floods, the fatalities were spread over three different locations; Lynmouth itself, Parracombe about 6 miles South West of Lynmouth and at Filleigh about 22 miles South of Lynmouth where a group of scouts who were camping were affected (Delderfield, 1981). These zones appear to be represented as zones 1 to 3 within the Lynmouth data used to calibrate the *Risk to People* model.

Fatalities in this event were caused primarily by the severity of the hazard with reports of people being swept away by the flood waters or being trapped or plunged into the flood waters when the buildings failed. Indeed, 22 of the 34 overall deaths reported during this flood event were killed when the buildings they were in collapsed around them. One main factor in this event leading to the deaths were the fast onset of the floods. Although very heavy rainfall had been observed on the 15th August itself and for preceding days, there was no real concern about the possibility of a large flood event. The fact that its full force occurred after dark was another factor leading to residents being caught unawares. However, the major factor leading to the high numbers of casualties, and particularly in Lynmouth, was the severity of the event. The large volume of fast flowing water, with a large amount of associated debris, caused the destruction of properties and meant that anyone unlucky enough to be swept away had very little chance of surviving. It was estimated that in the weeks that followed the disaster 100,000 tons of boulders and sediment was removed from the village (Delderfield, 1981; p81). The ferocity of the flood is also illustrated by the difficulty in recovering some of the bodies of those who had died, some were not found until weeks later and miles away from where they had gone missing; four of the victim's bodies were never found.

What should also be considered with the Lynmouth event are the large numbers of people who, despite terrible flood conditions, still managed to escape and survive. The information used to calibrate the *Risk to People* model for this event states that there were a total of 400 people living in the floodplain (Nz score) in all three of the flood zones. Despite this there is evidence that there were considerably more people exposed to the hazard during the flooding. As it was a very popular tourist area there were many visitors to the area who were caught up in the flooding; Prosser (2001) estimates that on the afternoon before the flooding there were 1,700 people in the village of Lynmouth. Although not all of these people would have been staying in the areas threatened by the flood waters, it is stated that around 700 survivors were evacuated from Lynmouth alone to higher ground in Lynton following the flood (Prosser, 2001; p39). These people managed to survive by sheltering on top-floors of properties (and were fortunate enough not to be in a property that collapsed) or by evacuating the zones immediately next to the river and moving to higher ground. In spite of the poor conditions and problems in communication, successful efforts were made by the local police, firefighters and ordinary citizens to rescue people trapped in buildings.

Table 5.1: Causes of death in the UK calibration events

Flood event	**Number of deaths**	**Cause of death (M = male, F=female)**	**Sources of data**
Gowdell (2000)	No deaths	N/A	n/a
Norfolk (1912)	4	• A baby drowned (M5 months). He was in a boat with his family, when it sank and he was lost when his mother became unconscious • 1 man drowned after becoming exhausted after wading through the waters to rescue many people who were trapped in their houses • 1 post man drowned when driving horse and cart through deep water • 1 lady died of 'fright' while being carried into a boat	Eastern Daily Press (2004)
Lynmouth (1952)	34	There were a range of deaths in Lynmouth and the surrounding area. **Lynmouth deaths (28)** A number of deaths were characterised by the collapse or partial collapse of six buildings and therefore perished from injuries sustained in the collapse or subsequent drowning. • A disabled mother (64), her son (27) and her daughter and her husband and children (F32, M37, M11 and M9) and 2 visitors (M56 and F52) were all killed in a cottage collapse (the father (63) survived) • A family of four (M30, F32, M3 and M3 months) died when their cottage collapsed. • An elderly couple (M80 and F72) and her brother (78) refused to leave their property and were killed later when that cottage collapsed. • Two elderly women (75 and 77) died when the cottage they were in collapsed. • Two seasonal workers (F48 and F40) from Surrey disappeared from the Lyn Valley hotel and are believed to have been swept away when a section of the hotel collapsed. • The cook of the West Lyn Hotel (F60) was swept away when a section of that hotel collapsed. • Four victims, a grandmother (54), her grandson (8) and two women visitors that they had taken in due to the weather (21 and 22) were swept away trying to escape the flood waters when they fell through a gap where the road had collapsed. • Another woman (56) lost her footing and was drowned when trying to escape the flood waters. • A man (53) was swept away and drowned; whilst trying to rescue others. • The deaths of two people (an unidentified lady and a man of 50) are unaccounted for **Parraccombe deaths (3)** • Two holiday makers a mother (46) and her son (14) were killed when their chalet was washed away • A man (60) disappeared, believed to have been swept away and drowned, whilst trying to rescue others. **Filleigh deaths (3)** • Three Manchester scouts (M11, M11, M14) were swept away from their campsite and drowned	Prosser (2001) and Delderfield (1981)
Carlisle (2005)	3	• Two elderly women (79 and 85) died in adjacent flooded homes in Carlisle (had not signed up to the flood warning service despite being written to by the Environment Agency) • 1 man (63) died when a barn collapsed onto his caravan in Hethersgill, Cumbria	BBC News Website (2005); Environment Agency (2005c; 2006); Government Office for the North West (2005)

Before examining the main factors leading to the fatalities in the Carlisle flooding of January 2005, there is some confusion concerning the number of deaths that have been attributed to this event and which have been used to test the UK model. HR Wallingford (2005a, p34) state that there were three people who died in the Carlisle flooding, although the report does state that the third death occurred outside of Carlisle. The third fatality of the event, that of a 63 year-old male, occurred when part of a barn collapsed on to his caravan and this should really be attributed to the high-winds experienced at the time rather than the flooding (BBC, 2005; Government Office for the North West, 2005). Therefore it was perhaps more appropriate to contrast the output of the model with two deaths, rather than the three stated. Despite this, the model still performs relatively well for this flood event.

The physical characteristics of the Carlisle event contrast significantly with that of Lynmouth. Although 2,800 properties were flooded (Environment Agency, 2005c) and the numbers estimated to have been exposed to the flooding were more than 5 times the number exposed during the 1952 Lynmouth event, the rate of rise of the flood event was much slower, which afforded the opportunity for flood warning and emergency management procedures to be implemented and for people to be successfully evacuated. The two deaths in this flood event relate to two elderly women (aged 79 and 85) who despite being contacted on a number of previous occasions by the Environment Agency did not sign up to their flood warning system and therefore it appears that they were either not sufficiently warned about the event or did not (or were not able) to take action. In addition to the official warning, these women also did not respond to a direct warning from rescuers knocking on their doors (Environment Agency, pers. comm.) In this case it does appear that the age and vulnerability of these two flood victims contributed to their deaths. Despite this event contrasting greatly with that of the Lynmouth flood event, the *Risk to People* model appears to function effectively. Table 5.2 adopts the same approach as Table 5.1 above and looks in more detail at the factors leading to deaths in the Continental European data sets.

5.2.2 Continental European flood-related deaths

As Table 5.2 shows there were different factors leading to flood-related deaths in the wider European case studies. Over the 18 flood events where fatalities occurred, there were 74 fatalities in total, with drowning and the collapse of buildings appearing to be the main causes of death, although the circumstances surrounding fatalities differ. Precise information about all of the deaths is not available; however there is sufficient data on enough of the deaths to look in more detail at the breakdown of these fatalities and to comment upon how this influences the performance of the *Risk to People* model. For instance, the model assumes (through the people vulnerability component) that those over the age of 75 and the long-term ill are more vulnerable to flood events.

Gender

Analysis of gender has only been applied to 71 of the adult deaths that occurred in the events studied. Of these the gender of 63% (45 deaths) is known. Males make up the highest proportion of the fatalities, accounting for almost two-thirds of deaths during the flooding. These results are consistent with other studies that have investigated deaths from flooding in developed nations where males are considered to have a higher individual vulnerability (Jonkman and Kelman, 2005). Further analysis of the fatalities concludes that there are also some differences between genders concerning the circumstances of the fatalities. For those deaths where both the circumstances surrounding the death and the gender is known (n = 40) 30% of the males who died were outside and drowned. 22% of the deaths occurred during rescue attempts of some kind, whether of humans or animals. A further 30% of the male fatalities were from car-related incidents. This is similar to the female component where 24% of the deaths were car-related. Another 24% of females were outside of either a property or a vehicle when they died. However, the main location for female deaths was inside the property where 47% of women died from downing after being trapped, a further one death was considered to be from building collapse whilst in the home. This contrasts with the 9% of males who died within buildings or from building collapse respectively. These results also confirm the psychological literature which suggests that males have a tendency to take greater risks (Byrnes *et al.*, 1999), as outlined in Section 2.3.

Table 5.2: Causes of fatality in the European events

Flood event	No. of deaths	Cause of death	Sources of data
Fella a, Italy (1998)	1	1 (51, woman) swept away by flood her body was found 10km downstream two weeks later	Partner questionnaire
Fella b, Italy (1998)	1	1 (57, man) swept away and buried by sediments and debris flow	Partner questionnaire
Cassano Murge, Italy (2005)	7	5 members of the same family (mother, 49, Father, 52; children 27, 23, 14) swept away in their car when crossing a bridge that collapsed; 1 driver (24, man) swept away in his car by a small torrent; 1 other drowned in a small river during the flood	Partner questionnaire
Fortezza, Italy (1998)	5	5 tourists (German speaking family) were swept away in car when it was hit by a debris flow	Partner questionnaire
Calonge, Spain (2005)	1	1 woman (75) swept away by the floodwaters	Newspaper reports
Cambrils, Spain (2004)	3	A couple (49 and 44) and the brother of the woman (41) all Andorran. Main roads were closed but they continued their trip using a secondary road. The river dragged them when they tried to cross it in their car.	Newspaper reports
La Farinera, Spain (2000)	1	1 woman (83) drowned in her home	Newspaper reports
Magarola, Spain (2000)	4	2 died when their car fell into the river through a destroyed bridge 2 policemen died during the search for the first two victims	Newspaper reports
Duszniki Zdroj c, Poland (1998)	7	Drowning (but no other details)	Workers of the town Council
Klodzko Gmina c, Poland (1997)	1	1 man (64) drowned whilst he was trying to catch some boards carried by the water – there was some speculation that he was drunk	Workers of the town Council
Klodzko Town a, Poland (1997)	1	6 people drowned (5 men 41, 58, 60, 61, 81) and 1 woman (57). One of the men (81) did not want to be evacuated and stayed in his flooded apartment; one was visiting a friend and was swept away when he was leaving.	Workers of the town Council
Klodzko Town c, Poland (1997)	5		
Miedzylesie b, Poland (1997)	1	1 man (34) was sleeping when his bedroom was flooded and collapsed into the floodwaters	Partner questionnaire
Stronie Slaskie a, Poland (1997)	1	A man (45) drowned when washed from a bridge whilst he was rescuing children standing there.	Partner questionnaire
Troubky, Czech (1997)	9	7 older residents died from crush injuries as their buildings collapsed. A younger man was killed by a falling beam A ninth victim (who initially survived the collapse of her home) died in hospital a few days later The homes were constructed unfired clay brick	General report on the Floods in the Morava river basin and Dyje River basin in July 1997, Povodí
Olomouc, Czech (1997)	2	Drowned when trying to escape the floodwaters	Povodí Moravy Water Management Control Centre records
Otrokovice, Czech (1997)	1	Drowned when trying to escape on an inflatable bed	General report on the Floods in the Morava river basin and Dyje River basin in July 1997, Povodí and General Report on the floods in the Zlín area in July 1997, Zlín District Authrorities.
Dresden, Germany (2002)	1	Casualty due to collapsed building	Personal communication with the Office for the Environment, City of Dresden
Gard, France (2002)	23	5 deaths occurred due to the use of motor vehicles all in separate incidents (F46, F46, M52, M55 and M70) 7 people died inside their homes from drowning; the following died following a dike break on the Rhône (F84, F54, F67, F75 and F77) and the others died due to drowning from rising water levels in their homes (F52, F71 and F84) ; 2 died in their homes from heart attacks (F72 and M52) 3 people who were outside drowned (F46) and two of those were attempting to rescue animals (M35 and M?) 5 tourists were killed after they did not evacuate their campsites quickly enough (M42 and 2 children 2 and 6) and (M74 and F34) from a second campsite.	Review of newspapers, municipality services, post flood reports from the rescue services Lutoff and Ruin (2007)

Age

For the 74 fatalities that occurred during the European flood events we have age data for 60% of the sample. Figure 5.1 plots this aggregated age data, alongside a more general age curve for Europe. As can be seen, the majority of the fatalities are found between the ages of 40 and 60, with another smaller peak in the age category 70-79. This compares relatively well with the general age curve for the region suggesting that the age at which people died is a relatively good fit with the general demographic. The main outlier appears as expected to be with the older age group. This phenomenon would also be exacerbated by the inclusion of the flood event of Troubky where it is stated that 7 older residents died in their collapsing homes, but no specific ages are provided. If it is assumed that the term "older resident" applies to those above the age of 65, then the graph would be even more heavily weighted towards the older age groups. This is of importance as there is an age factor included within the "people vulnerability" component of the *Risk to People* model.

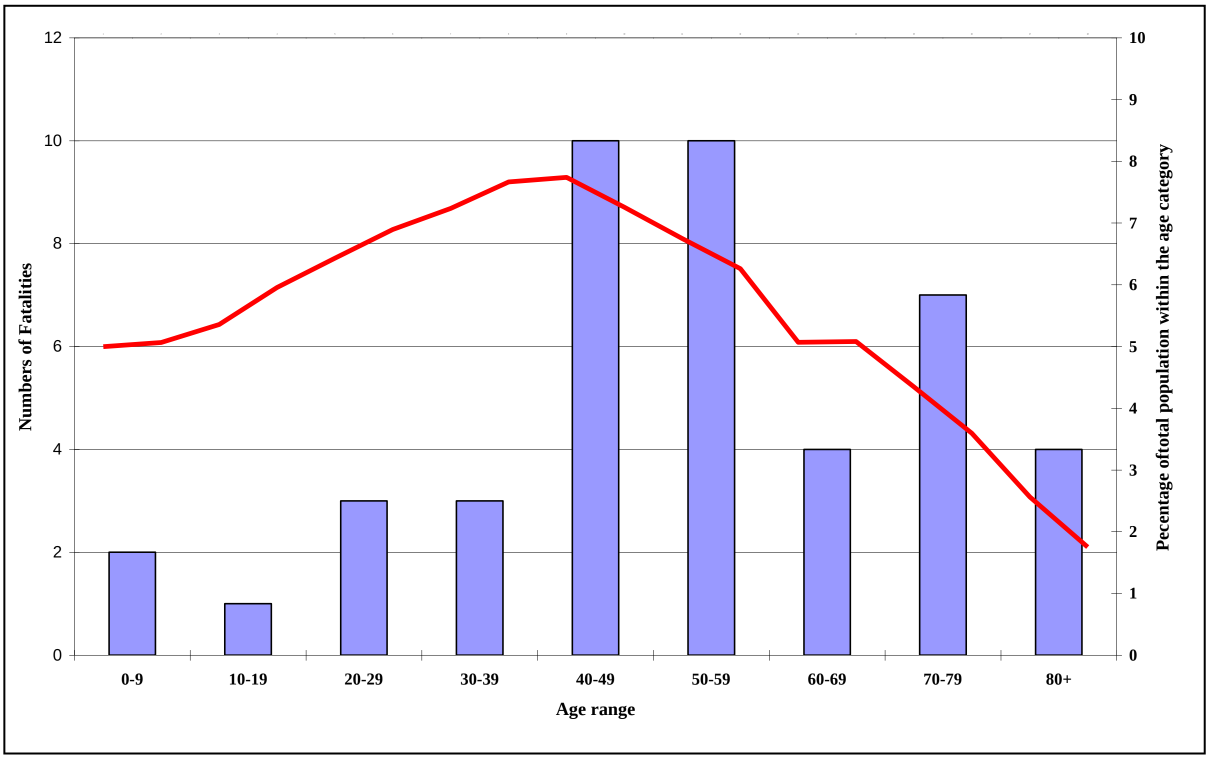


Figure 5.1: Graph of the ages of the fatalities in the European flood events plotted with a general age line[6] for the countries affected by flooding

It is also appropriate to analyse whether there are any other patterns in the age data concerned with the circumstances surrounding deaths. Where known, Figure 5.2 illustrates the circumstances surrounding the deaths of those people within each age category. The main points of interest within this graph are the importance of car-related deaths to those in the 40-49 age category, and the increasing importance of drowning within homes and properties as the ages of people increase. There is also a rise and then fall in the numbers of people who were killed by flooding in the outdoors, peaking in the 50-59 age category.

[6] *Note that the age line was drawn by calculating the percentages of the total population for each of the age categories. The line shows averaged data for 2006 of all of those countries where there are examples of flooding events (Czech Republic, France, Germany, Italy, Poland and Spain). The data was taken from the European Communities' EUROSTAT dataset http://epp.eurostat.ec.europa.eu.

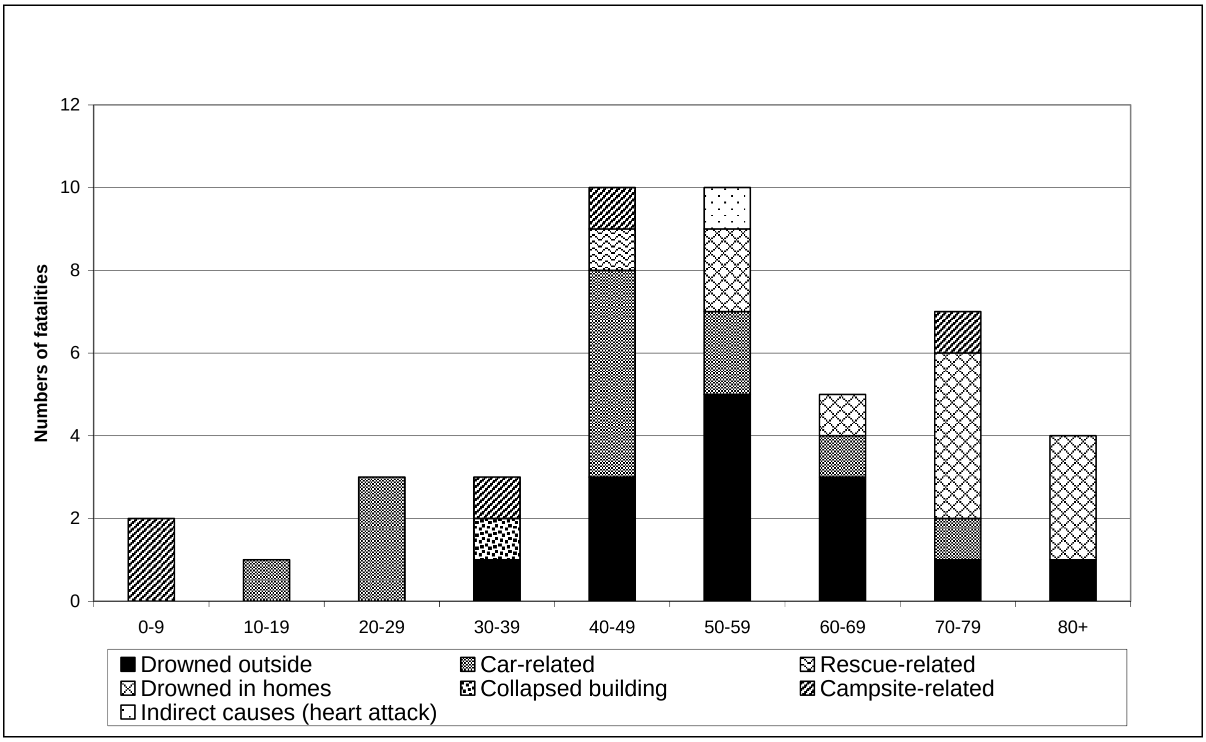


Figure 5.2: Circumstances surrounding flood-related death broken down by age for the European flood events

Although a more substantial analysis might have been performed if there had been more specific details surrounding the deaths from these events, the results that have been reported here are not significantly different from other studies of this kind (e.g. Jonkman, 2005; Jonkman and Kelman, 2005). It also provides some insight into those factors that need to be modelled within any attempt to estimate the risk to life from flooding events. Those datasets where there were no fatalities are also important to see whether there are any clear factors that are preventing injuries and deaths from flooding and to identify whether there are any additional factors that need to be included within a method for estimating loss of life from flooding.

5.3 Further factors leading to fatalities

The complex nature of flooding events and the differences that exist between the circumstances surrounding deaths means that it is important to try to find some common elements that are present to enhance the modelling of losses. Data on the flood characteristics of each of the events has been analysed alongside the actual circumstances of the fatalities to try to identify the main factors that are affecting the number of injuries and deaths (Table 5.3).

5.3.1 Human behaviour

As highlighted in Section2, actions taken by people have a large impact on the likelihood of fatalities from flooding. Many of the fatalities that have been observed in the European flood events were due to human behaviour and decisions taken by those in danger from the flood waters. Wilson (2006) cites a human-behaviour typology which describes how people can increase their own risk during flooding events. These factors relate to: people being trapped in cars, trying to rescue other people or pets, to trying to protect or recover assets, or related to the excitement of major floods (Wilson, 2006, p57). Each of these types of behaviour was exhibited in the European case studies examined.

*Table 5.3: Prominent factors affecting death in both the UK and wider European flood events (**XX** = Most important factors)*

Flood event	Flood Velocity	Speed of onset	Debris Content	Structural Collapse	Rescue-related	People Vulnerability	Human Behaviour	Awareness/Language difficulties	Timing of flood	Cause of death
Norfolk, UK (1912)	**XX**				**X**		**X**			A baby drowned (M5 months) after boat he was in capsized; a man drowned attempted to rescue others, a man drowned when driving horse and cart through deep water and a lady died of 'fright' while being carried into a boat
Lynmouth, UK (1952)	**XX**	**XX**	**X**	**X**					**X**	Range of deaths but most were either swept away by the flood waters, hit by debris or trapped in collapsing buildings (see Table 7.1 for more details)
Carlisle, UK (2005)						**XX**	**X**	**X**		Two elderly ladies (79 and 85) died in adjacent flooded homes in Carlisle a man (63) died when a barn collapsed onto his caravan in Hethersgill, Cumbria
Fella a, Italy (1998)	**XX**									1 (51, woman) swept away by flood her body was found 10km downstream two weeks later
Fella b, Italy (1998)	**X**		**XX**							1 (57, man) swept away and buried by sediments and debris flow
Cassano Murge, Italy (2005)	**X**			**X**			**XX**			5 members of the same family (mother, 49, Father, 52; children 27, 23, 14) swept away in their car when crossing a bridge that collapsed 1 driver (24, man) swept away in his car by a small torrent 1 other drowned in a small river during the flood
Fortezza, Italy (1998)		**XX**	**X**				**XX**	**X**		5 tourists (German speaking family) were swept away in car when it was hit by a debris flow
Calonge, Spain (2005)	**X**					**XX**				1 woman (75) swept away by the floodwaters
Cambrils, Spain (2004)							**XX**	**X**		A couple (49 and 44) and the brother of the woman (41) all Andorran. Main roads were closed but they continued their trip using a secondary road. The river dragged them when they tried to cross it in their car.
La Farinera, Spain (2000)	**X**					**XX**				1 woman (83) drowned in her home
Magarola, Spain (2000)				**X**	**X**		**XX**			2 died when their car fell into the river through a destroyed bridge 2 policemen died during the search for the first two victims
Duszniki Zdroj c, Poland (1998)	**X**									Drowning (but no other details)
Klodzko Gmina c, Poland (1997)							**XX**			1 man (64) drowned whilst he was trying to catch some boards carried by the water – there was some speculation that he was drunk
Klodzko Town a, c Poland (1997)	**X**					**X**	**X**			6 people drowned (5 men 41, 58, 60, 61, 81) and 1 woman (57). One of the men (81) did not want to be evacuated and stayed in his flooded apartment; one was visiting a friend and was swept away when he was leaving.
Miedzylesie b, Poland (1997)				**XX**		**X**			**X**	1 man (34) was sleeping when his bedroom was flooded and collapsed into the floodwaters
Stronie Slaskie a, Poland (1997)				**XX**	**X**					A man (45) drowned when washed from a bridge whilst he was rescuing children standing there
Troubky, Czech (1997)		**X**		**XX**						7 older residents died from crush injuries as their buildings collapsed. A younger man was killed by a falling beam, A ninth victim (who initially survived the collapse of her home) died in hospital a few days later, The homes were constructed of clay brick
Olomouc, Czech (1997)	**X**									1 drowned when trying to escape the floodwaters
Otrokovice, Czech (1997)	**X**						**X**			1 drowned when trying to escape on an inflatable bed
Dresden, Germany (2002)				**XX**						1 was killed in a collapsed building
Gard, France (2002)										5 motor vehicles deaths (F46, F46, M52, M55 and M70), 7 drowned in homes, (F84, F54, F67, F75 and F77) died in a dike break drowned after water in homes (F52, F71 and F84), 2 died in their homes from heart attacks (F72 and M52) 3 people who were outside drowned (F46) and two of those were attempting to rescue animals (M35 and M?) 5 tourists were killed in campsites (M42 and 2 children 2 and 6, M74 and F34)

Car-related fatalities

In the cases examined here thirteen deaths from flooding were car-related. Vehicle-related deaths appear to be a major factor leading to loss of life in European events. As outlined in Section 2, driving cars through floodwaters is a significant cause of death during flood events (Jonkman and Kelman, 2005; Poole and Hogan, 2007; Drobot *et al., forthcoming).* In the flooding in Cambrils, Spain in September 2004, three Andorrans ignored warnings about the flood, and when the main road was closed, continued their journey using a secondary road. They were killed when their car was dragged away by the floodwaters when they tried to cross the river.

However, not all instances where people drive through floodwaters could be considered reckless. The European events also highlight where people have become flood victims when they have not directly tried to drive through or close to flood waters. Another Spanish event provides an example of this. Two of the flood victims who died in the Magarola flooding in June 2000 were travelling in their car across a bridge which collapsed. In Magarola, the other two victims that were killed were policemen who were searching for the people in the car.

Rescue-related behaviour

Rescue obviously has both negative and positive influences upon the numbers of people who are killed or seriously injured from flooding. The Boscastle case study (Section 6.4) illustrates the positive side of rescue, whereby the actions of a large number of people effectively prevented fatalities. This is not always the case however. Five people were reported to have died from rescue-related incidents during the Continental European flood events, two of which were reported to have been rescuing pets from the floodwaters. What of course is not recorded are the numbers who might have died if it were not for these actions and from successful rescue attempts. For example, in the Stronie Slaskie it is reported that a man perished when rescuing some children from a bridge.

Asset protection and recovery

There are a number of incidents reported during the European flood events whereby people were reluctant to leave their properties. This reluctance to leave and a refusal to evacuate may be for a variety of reasons. These reasons include: not believing that the flooding will impact upon them, a failure to understand the seriousness of the situation, or the desire to remain with their properties to protect them from the floodwaters or to protect them from looters following the flooding. This is the case with many of the Polish events as it was reported that “some people did not want to be evacuated because they did not want to leave their houses and all their possessions as they were afraid of being robbed” (Arup, 2006; p6). In Klodzko Town which flooded in July 1997 an 81 year old man was killed when he did not want to leave his apartment, which subsequently flooded.

5.3.1 Time of day and seasonality of flooding

The timing of a flood was discussed in Section 2.3.1. The Boscastle case study which is discussed in some detail in the next Section is illustrative of the difference that time of day can make. Another example of a flood event where the seasonality exacerbated the problem was in the Gard region of France in June 2002, discussed in Section 5.5 below.

5.3.2 Structural collapse

Section 2.3.3 raised the issue of building characteristics as a factor affecting risk to life. One of the other significant causes of death from flooding appears to be from the structural collapse of buildings, either directly leading to death or preventing escape from the floodwaters. This appears to be more relevant in Continental European flooding than it is in UK flooding, where the only major flood incident where building collapse has been important was in Lynmouth, 1952. This is due to the faster and deeper waters experienced in some parts of Europe. Differences in building type, materials and construction methods are important in determining whether a building will be severely damaged or destroyed by flood waters. Figure 5.3 is a photograph taken following the flooding in Troubky, Czech

Republic. All nine fatalities in this event were caused by structural collapse. In this case building materials consisted of non-fired bricks.

Figure 5.3: Photograph of the destruction to properties following the 1997 flooding Troubky
© Nové Přerovsko

Buildings are not the only problem when considering structural collapse. A number of people within the European floods lost their lives when either roads or bridges that they were travelling on were destroyed. Again the numbers of people who are killed in these types of circumstances are difficult to predict due to the fact that the numbers of people within a collapsed building or travelling over a bridge when it fails are extremely variable.

5.3.3 Role of chance

The difference between surviving and not surviving a flood event may be strongly influenced by random, unpredictable factors. For instance, the presence/absence of floating debris that can be clung to, and the availability of shelter, are largely a matter of luck (Aboelata *et al.*, 2003). Therefore, although it might be possible to estimate and define the broader risks to society from a flood event, it is extremely difficult to estimate risk to an individual. With small numbers of fatalities being recorded, fortuitous or unfortunate circumstances leading to more or fewer fatalities may greatly impact upon the total recorded numbers of deaths. More details from the case studies on the role of chance are given in Sections 5.4.4, 6.4.2 and 6.4.3 below.

5.4 Characteristics of datasets with no fatalities

In addition to examining the circumstances surrounding fatalities in the 21 flooding events where there have been deaths, it is also important to examine those 18 zones in Poland and 3 cases in Germany for which data are available where flooding was experienced yet no deaths occurred. These examples can be split into two separate groupings, those that are zones from a hazard location where deaths were experienced (in the cases of Stronie Śląskie, Klodzko Town, Klodzko Gmina, Duszniki Zdroj and Meidzylesie) and those from locations where there were no deaths at all were experienced (Ladek Zdroj, Bystrzyca Klodzka and Polanica Zdroj (Poland) and Erlln, Grimma and Eilenburg (Germany)).

The low numbers of people exposed to the flooding is one reason why no deaths occurred in a number of the flood events. The flood event in Klodzko Town zone B affected industrial areas where there is no residential population and the numbers of people in the area was also low due to the timing of the flood being at night and on a holiday. Similarly, the populations exposed in other zones is low, as the data shows that Stronie Slaskie C, Klodzko Town B, Duszniki Zdroj A, Ladek Zdroj C, Polanica Zdroj B and Dresden B are areas of industry, farmland, forest or meadows where no or few people were exposed.

There are however a number of events occurring in areas that have relatively large populations exposed which also reported zero deaths. Table 5.4 shows the data collected from these events in order to investigate more fully possible intervening factors. In all of the zones it was reported that there were few or no language difficulties and the speed of onset was considered to be a medium risk (i.e. the rise of the flood water occurred over a few hours). Data was also collected on the presence or absence of debris in the flood waters and for all of the data sets in Table 5.4 large debris was observed during the flood, including such objects as cars, trees, rocks and parts of damaged buildings. As can also be seen the hazard ratings that have been calculated for each of the zones are comparable to those flood events where fatalities did occur, therefore it can be argued that the flood events are severe enough and have the flood characteristics for deaths to have occurred. It is difficult, if not impossible, to state with certainty why the flooding in these zones did not lead to any deaths. However the analysis in this section aims to identify those common factors that might have contributed to the fact that the populations exposed managed to survive the flood waters.

5.4.1 Rural properties

A number of the risk zones (Bystrzyca Klodzka A, Klodzko Town D, Klodzko Gmina A, Klodzko Gmina B, Lazek Zdroj B, Lazek Zdroj D, Meidzylesie B and Stronie Śląskie B) where no deaths occurred were located in more rural areas. These areas obviously have different characteristics to urban areas, such as often smaller populations at risk and a lower concentration of buildings and domestic properties. The more scattered nature of these settlements may mean that floodwaters are more able to spread out over the floodplain, thereby dissipating energy, resulting in the waters being less likely to cause injury and death. In addition, due to the increased amount of space the influence of debris in the water might be reduced as there is more space for debris to move between properties. This argument is further supported by the fact that of the 19 zones where flood deaths occurred only 5 were classed as rural areas or areas of scattered settlement, and a further 3 were mixed (urban and rural zones).

5.4.2 Type of buildings

Another explanation related to the type of properties within the risk zone. Ten out of the sixteen zones where no deaths occurred had predominantly multi-storey houses. This means that there were areas for people to escape the floodwaters until either the flood waters subsided or they were rescued or evacuated. However, this situation is of course also present within those datasets where deaths were recorded (12 of these zones either have multi-storey properties or mixed). This variable is accounted for to some extent within the original *Risk to People* methodology where the nature of the area (including the types of buildings and houses) are adopted within the Area Vulnerability component.

Table 5.4: Data for those events where no deaths occurred - key characteristics are shown in ***bold***

Flood event	**FLOOD CHARACTERISTICS**					**AREA CHARACTERISTICS**					**PEOPLE CHARACTERISTICS**		
	Depth (m)	Velocity (m/s)	Hazard Rating	Time of Flood	Duration	Land use	Flood warning system	Type of Buildings	Building collapse	Evacuation	Population	Age 75+	Risk Awareness
Bystrzyca Klodzka A	5	10	53.5	Night, holiday	1 day	Urban	None	**Multi-storey houses**	None	**630 people evacuated over the two zones**	450 (est)	25	Low
Bystrzyca Klodzka B	2	5	12	Night, holiday	1 day	**Rural, fields, forest**	None	Single-storey houses	2		1050 (est)	60	Low
Duszniki Zdroj B	4	10	43	Evening/ night	12 hours	Tourist and recreation	None	**Multi-storey (including guesthouses, hotels, restaurants, parks stadium)**	None	None	450 (est)	150	Low
Klodzko Town D	4	Up to 5	23	Night, holiday	2 days	Industrial, fields	**Warned by the municipal police by megaphones**	Two sports stadiums, single-storey houses, railway track, storehouse	None	Some attempts, but few wanted to leave	30 (est)	5	Low
Klodzko Gmina A	2	5	12	Late evening/ night holiday	3 days	**Rural (fields mainly)**	None used	Single, single-storey houses	None	People evacuated after the flood event	120 (est)	10	Low
Klodzko Gmina B	3.8	5	21.9	Late evening/ night holiday	2 days	**Rural; forests and fields (majority)**	None	Single-storey houses, scattered	1	None	100 (est)	7	Low
Ladek Zdroj A	3	5	17.5	Noon/ afternoon	24 hours	**Rural, scattered settlement**	**Warned by the municipal police by megaphones**	**Two-storey houses**	1	**Evacuation was announced - 10 evacuated**	180 (est)	14	Low
Ladek Zdroj B	4.6	5	26.3	Noon/ afternoon	24 hours	Urban, concentrated settlement	**Warned by the municipal police and fire brigades by megaphones– also radio warnings**	**Multi-storey buildings**	None	**Evacuation was announced - 60 Evacuated**	250 (est)	20	Low
Ladek Zdroj D	2	5	12	Noon/ afternoon	24 hours	**Rural, scattered settlement**	**Warned by the municipal police and fire brigades by megaphones– also radio warnings**	**Two-storey buildings**	None	Evacuation announced but no-one was evacuated	300 (est)	22	Low
Meidzylesie A	2.5	10	27.25	Middle of day, holiday	12 hours	Concentrated settlement	None	**Multi-storey houses**	1	None	370 (est)	35	Low
Meidzylesie B	1.5	10	16.75	Middle of day, holiday	12 hours	**Fields, meadows, forest single buildings**	None	Single, single-storey buildings	None	None	140 (est)	12	Low
Polanica Zdroj A	5	10	53.5	Late evening, night	12 hours	Urban concentrated settlement	**Warned by the municipal police by megaphones**	**Multi-storey houses (majority)**	3	None	420(est)	30	Low
Stronie Śląskie B	2	10	22	Night time, holiday	3 days	**Rural, fields**	**Warned by the municipal police and fire brigades by megaphones– also radio warnings**	Single-storey houses (ground floor plus an attic)	None	**People evacuated after the flood event**	400 (est)	100	Low
Erlln	1.6	4	7.7	Morning	3 days	Residential	**No official but 25% received an 'unofficial' warning**	**Detached houses (mainly two storeys)**	None	None	100 (est)	19	Medium
Grimma	3	7	23	Afternoon	3 days	Mixed use (city centre with commercial, residential etc)	**People warned by the police at around midnight, the peak of the flood did not occur until 2pm the following day**	**Mostly 2-3 storey houses, schools, churches. In the main streets: shops in the ground floor, residential in the upper floors**	50	**None organised, but 100 people needed to be rescued post-flood**	1200(est)	100	Low
Eilenburg	2	4	10	5-6pm	12 days	Residential	**Very good. Reported that 98% of people warned by police 5 hours before the flood**	**Detached houses, mainly two storeys**	None	**Most people left 5 hours before the flood**	250-300 (est)	55	Medium

5.4.3 Evacuation and flood warning

An important aspect that might explain why, despite high hazard ratings in many of the floods, no fatalities were experienced was the presence of both flood warnings (thereby alerting people to the threat of flooding) and/or evacuation (either pre- or post-flooding). Nine out of the sixteen cases where no deaths were experienced reported some kind of flood warning prior to the onset of flooding, whether formally or informally delivered. This might be a significant factor about why people were able to take appropriate action and therefore reduce the loss of life.

Evacuation is also a significant factor leading to the situation where there were no deaths. Seven out of the sixteen zones reported that there was some evacuation either prior to the flood or directly afterwards (thereby avoiding the possibility of subsequent flood-related deaths). The levels and timings of the evacuations vary considerably between hazard zones. Table 5.5 shows those zones where evacuation was present and also the levels of this evacuation.

Table 5.5: Risk zones where evacuation was undertaken or attempted

Risk zone	Evacuation	Percentage of the population evacuated
Bystrzyca Klodzka A & B	630 people evacuated over the two zones	42%
Ladek Zdroj A	Evacuation was announced 10 evacuated	6%
Ladek Zdroj B	Evacuation was announced 60 Evacuated	24%
Stronie Śląskie B	Some people were evacuated after the flood event	unknown
Grimma	None organised, but 100 people needed to be rescued/evacuated post-flood	8.33%
Eilenburg	Most people left 5 hours before the flood	c. 95%
Klodzko Gmina A	People evacuated after the flood event	Unknown
	Attempted evacuation	
Klodzko Town D	Some attempts at evacuation but few wanted to leave	--
Ladek Zdroj D	Evacuation announced but no-one was evacuated	--

Evacuation appears to be highly significant in at least three of the risk zones. The zones of Bystrzyca Klodzka zones A and B had a total of 630 people evacuated out of a combined risk population of 1500 people. This equates to 42% of the ‘at risk’ population. The depths (5m and 2m respectively) and velocities (10 m/s and 5 m/s respectively) of flooding in these areas were severe enough to cause loss of life and therefore it is likely that the removal of nearly half of the population (most likely from the most at-risk areas) has meant that loss of life was prevented in these cases.

Similarly, the case of the town of Eilenburg in the Mulde region of Germany is another case where evacuation proved to be successful at preventing injury and death from flooding. It was reported in this case that 98% of the population received a warning to evacuate some 5 hours before the flooding occurred and that most responded positively to this warning and evacuated the hazard zone some hours before the flooding occurred.

Although it is possible to surmise that in these cases evacuation has had a positive impact upon the numbers injured and killed (either directly or indirectly) by floodwaters, it is of course very difficult to analyse the impact of the evacuation of the population in unofficial or informal evacuations, as in these cases the exact numbers leaving the area are often not known. In addition it was reported that in a few of the zones an evacuation was ordered but for a number of reasons people were reluctant to leave their homes and evacuate.

In addition to the positive impacts of evacuation there is also the possibility that the act of evacuation might in fact increase a person's likelihood of injury or death. An examination of those who died highlighted that those in the lower vulnerability categories (e.g. those who are not elderly or those not hampered by illness or disability) are in most floods more likely to be killed or injured if they are outside of their home or in their cars during the flood (Jonkman and Kelman, 2005; Drobot *et al., forthcoming*). Thereby undertaking evacuation at inappropriate times (e.g. when the floodwaters have risen in depth and velocity) and of those who are not threatened by staying in their own homes (e.g. by building collapse or deep water) are often increasing their chances of death by evacuating.

In the zones examined where there were no deaths, warning and evacuation appear to have had a great impact on ensuring that there were no fatalities associated with the flooding. However flood warnings and evacuations are also present within the datasets where deaths occurred. Nine out of the nineteen risk zones had some evacuation present, ranging from 2% in the case of Olomouc to almost 100% in the Magarola zone. Both of these events had evacuation post-flooding and therefore looking at the nature of the deaths in these cases it appears that the flood fatalities occurred prior to the evacuation. Indeed, only the cases of the Italian flood in Fella (both zones A and B) report that evacuations occurred prior to the flooding. Therefore, it can be concluded that the effectiveness of the evacuation procedures in preventing fatalities is very closely linked to both the type and characteristics of the flooding as well as the timeliness of the evacuation and associated flood warning.

5.4.4 The role of chance

In addition to the presence of the variables described above (or a combination of these variables) there is also likely to be an element of chance as outlined in Section 5.3.4 above. The case study of the flood in Duszniki Zdroj Zone B could be an example of where this played a part.

On the face of it the circumstances of this flood suggest that loss of life and significant numbers of injuries would be experienced. For example, the area is one which has high degrees of tourism and recreation and it has been noted that there are large numbers of guest houses and hotels located within the risk zone. The flood experienced was also close to the height of the tourist season in July 1998 and began in the late evening/night. There were no official flood warnings and the time of day (the flood started in night time of a public holiday) may have meant that observations of the flood waters rising could have been hampered. In addition to the large numbers of visitors (which one would assume had low flood awareness) there were also large numbers of elderly people among the 'at-risk' population. It was estimated that a third of the resident population in the area were over the age of 75.

It can therefore only really be speculated as to why, with a flood of up to 4 metres depth with velocities up to 10 m/s, there were no recorded deaths. Perhaps the presence of large numbers of visitors (with little or no experience of flooding) meant that they followed the advice of officials dealing with the flood or the advice and instructions of the local people. The presence of large numbers of elderly people again may have meant that they received more assistance than others during and following the event, after it was recognised that they might be more vulnerable to the effects of flooding. Another explanation might be that because many of the population were visitors or elderly this meant that fewer of these people took risks to save property, belongings or pets, or ventured out to assist relatives or neighbours during the flood. Moreover, since the number of building collapses caused by this flood were zero, those who remained within multi-storey hotels and residences were likely to be safer than those who might have ventured outside for whatever reason.

5.5 Case study: Gard flash flooding France, 2002

The Gard flood of 2002 is an example of severe flash flooding over a wide area. The case study contributes by helping to identify the factors leading to risk to life and in understanding the relation of risks to people and hazards. It provides data about casualties and public awareness of flash flood events in the Gard département in order to contribute to the development of the Risk to Life model. Much of the research relating to the case study was conducted as part of a PhD thesis for one of the authors (see Ruin, 2007). A separate report containing a more detailed discussion of the case study is available on the FLOOD***site*** website (Lutoff and Ruin, 2007 - Project Report Number T10-07-03).

The Gard region is a flash flood prone *département* located at the foothills of the Cévennes mountains close to the Mediterranean sea, in Southern France. Due to the nature of the flooding (i.e. small catchments with very short response times) it is not possible to issue flood warnings. The hydrometeorological circumstances leading to fatalities during the September 2002 flash flood event were analysed and focus was given on social vulnerability factors and especially risk awareness linked to motor vehicle usage in heavy rain conditions.

The disaster area covered 297 municipalities (80% of the Gard department), taking 23 lives. Lutoff and Ruin (2007) report fatalities were mostly old and disabled people (9 of them died in their homes), and road users (5 people). During this event tourists also appeared to be vulnerable with a total of 5 victims, two of whom were children, who perished when they were not able to evacuate their campsites quickly enough. About 600 vehicles were involved in the operation rescuing 2,940 people. 40 of these vehicles were lost and 200 were damaged. 1,260 people were rescued by 20 helicopters. The flood event started on a Sunday night when fewer people were on the roads compared to weekdays. Considering that more than 200 school buses transporting 4,000 children circulate on week days in this sector, this gives an indication of the potential risk. Thus, if the flood had happened during the height of the tourist season and during a week day, many more fatalities are likely to have occurred.

Even if the number of injuries and fatalities are known, it is very difficult to be precise in terms of geographical location and time. People affected at home represented only one part of the casualties. 60% of them were not at home during the flood and it is sometimes difficult to understand the circumstances of these casualties. The age factor does not seem to be significant in the case of road fatalities in flash flood events. Risk awareness on roads is not necessary related to global awareness of risk. When dealing with motorist fatalities, behaviour seems to be more relevant, but also difficult to investigate. In a previous study (Ruin and Lutoff, 2004) it was shown that mobility in the context of flash floods is mostly linked to commuting. Therefore, it may be interesting to investigate road users' everyday itineraries and their spatial representations.

The authors conclude that mobility is one of the main circumstances of fatalities and that a way should be found to include this in the risk to life model. In fact, on road networks, major danger is less localized along large rivers than at the crossing of minor tributaries often invisible in dry periods. It was assumed that flash flood hazard specificities may be one of the significant factors leading to difficulties for individuals and particularly motorists to perceive danger on their usual journey itinerary. At the same time, in the Gard *département*, people in charge of road networks and emergency managers struggle to protect road users in crisis situations. Although they have developed technical solutions and emergency plans, none of these addresses the question of peoples' perception and knowledge of protection measures.

5.6 Recommendations for model refinement

The complex circumstances that surround how and why individuals are casualties of flooding make it difficult to assess and model an individual's risk from an event. However, the analysis of the circumstances leading to fatalities from flooding in the examples examined highlights that there are some potential differences between the significant factors causing deaths in the UK and those in other parts of Europe. It is therefore necessary to provide some recommendations for refinement of the *Risk to People* methodology to make it more applicable within a wider European context. A number of factors need to be considered when making these recommendations:

- *People vulnerability should be given less prominence:* due to the more severe and different types of flooding that occur in Europe the vulnerability components may not be as relevant in the wider European context. This is especially the case with flash flooding where the flood waters have high velocity and depth, therefore anyone caught up in these waters will be vulnerable. The analyses on age indicates that those who appear to be most vulnerable (e.g. the elderly) are often no more vulnerable than others, therefore the degree to which this is useful for the model, particularly with regard to flash flooding, needs to be questioned. Indeed, there is some evidence to suggest that in certain circumstances more elderly people might be, by their behaviour, less vulnerable as they are more likely to recognise their own limitations and remain inside away from the flood waters, whereas other younger more able-bodied people might venture outside. In some flood events it might be wiser for people to stay within their properties if they are not able to evacuate from the area prior to the floodwaters arriving.

- *Place more prominence on the effect of flood warnings:* the analysis of those flood events where no deaths occurred illustrates the potential importance of both official and unofficial flood warning systems. Although official warning is included within the *Risk to People* methodology, this might be having a more important impact than the model is currently recognising.

- *Place more prominence on type of buildings:* from the analysis of the ‘no death’ events the presence or absence of two-storey buildings is recognised in having an impact on the loss of life. Again this is partly included within the current methodology, within the nature of the area component. However, the model could be altered slightly to strengthen this component.

- *Include a population density factor:* the density of properties in an area and the land use appear to have an impact upon whether flooding causes fatalities. Therefore, it would be interesting to investigate whether it is possible or significant to put in a measure of urban density to reflect whether it is a rural or urban landscape that is being affected.

- *Place more prominence on the debris factor:* within the original *Risk to People* model a factor for the presence or absence of debris is included. This factor may be having a greater influence on the likelihood of fatalities in Continental Europe and therefore the significance of this factor should be examined. In particular, whether the presence of debris is more likely to lead to building collapse needs to be explored.

This analysis of the circumstances surrounding how people actually died from flood events highlights the many different factors that can lead to fatalities from flooding. Due to this complex suite of circumstances, and the fact that the original *Risk to People* model is currently not predicting deaths very accurately in the wider European floods, this leads to questions concerning what the model should actually be producing and the level of refinement that is possible. This will be discussed further in Section 8 when investigating alternative models for assessing risk to life from flood events in Europe.

Before discussing the possible revisions to the *Risk to People* model, the following Section focuses on a detailed case study of the 2004 Boscastle flood in England which illustrates and helps understanding of a number of the issues and factors discussed in the preceding Sections.

6. Boscastle Case Study

The case study of the Boscastle flooding in August 2004 has been chosen for inclusion in this report for a number of reasons. Firstly, it provides another UK case study from which to calibrate the UK-derived *Risk to People* model and also shares similarities with many Continental European flood events. It is an event with some similarities to that of Lynmouth in 1952 (although the meteorological factors are considered to be different, (Environment Agency, 2005b)). The Lynmouth flood formed part of the basis for the calibration of the original model and was therefore modelled by the *Risk to People* methodology with some success. Therefore it might be anticipated that the *Risk to People* model should perform well when applied to this case study. The Boscastle case study however is situated within the context of modern flood warning practices, incident management and search and rescue scenarios. In addition, illustrating the process that is used to apply the model will highlight some of the issues surrounding the data collection process and the gathering of the data points required by the model. Thirdly, the Boscastle flood can be used to highlight how a series of circumstances and the efforts of rescuers can greatly alter the chances of experiencing fatalities from flood events.

6.1 Summary of the flood event

Boscastle is a small village located on the North Coast of Cornwall in the South West of England (see map in Figure 6.1). The flood event is well-documented (see Rowe, 2004; Environment Agency 2005c; HR Wallingford, 2005b; South West Resilience Forum, 2006) therefore only a brief summary will be presented here. Severe flooding occurred in the River Valency and Crackington Streams following very heavy rainfall (200mm in approximately 5 hours) occurring between 12:00 and 16:00 GMT on the 16th August 2004 (HR Wallingford, 2005b). Both of the main catchments causing the flooding are flashy in nature with steep-sided valleys leading to the villages of Boscastle and Crackington Haven, thereby funnelling the rainwater and converging in the towns themselves. The heavy rainfall occurring that day and the nature of the topography meant that within around three hours the River Valency began to overspill its banks. The flood peak was considered in Boscastle to be at 17:00 only some 5 hours after the rain started (North Cornwall District Council 2004). The flood waters were severe enough to badly damage some residences and completely destroy others. In addition, cars were transported by the flood waters from the visitors' car park down the main stream, out into the harbour and out to sea (Environment Agency, 2005c). At its peak the River Valency was estimated to have a discharge of 180 cubic metres per second (Environment Agency, 2005c).

One of the major characteristics of the flooding was the speed with which the waters rose. The post-flood analysis completed by HR Wallingford (2005b) considers this to be due mainly to the blocking of bridges by debris and also their subsequent collapse, as well as the collapse of other structures such as walls that were initially holding back some of the flood waters. These effects were coupled with the changes in routing of the flood waters around obstacles which added to the sudden changes in water level.

The fast and deep nature of the flood waters and the fact that there was little or no warning of the flood event meant that there were many people trapped in Boscastle, mainly within the residential and commercial buildings. The search and rescue effort that followed was extensive and is discussed in more detail in Section 6.4.

There are various estimates of the total damages from the flooding. The North Cornwall District Council (2004) put a figure of up to £2 million on the cost of repairing and replacing damages to infrastructure and buildings. Rowe (2004) states that one insurance estimate put the cost of the flood damage at £50 million. Post-flood analysis of the event in the Boscastle area suggested that it had a return period of 1 in 400 years, whereas the Crackington Haven area was less extreme with a 1 in 100 year event.

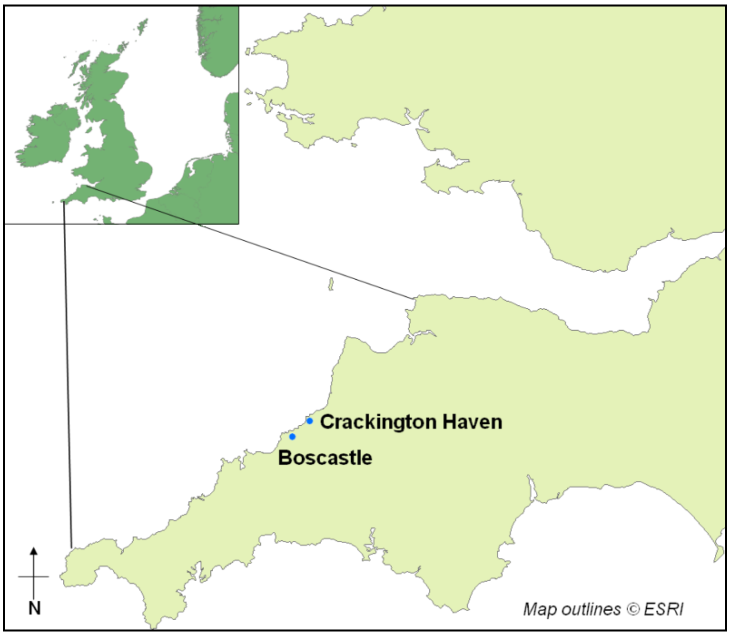


Figure 6.1: Map of the locations of Boscastle and Crackington Haven

6.2 Application to the Risk to People Methodology

The Boscastle flooding event is useful because much information is available. The number of visitors to the area in conjunction with the presence of the emergency services, and subsequently the media, means that there are many eye-witness accounts and the event itself was well-documented. Consequently there have been a number of publications detailing the causes of the flood, the flood event itself and the aftermath (North Cornwall District Council 2004; Rowe, 2004; Environment Agency, 2005c; HR Wallingford, 2005b; South West Resilience Forum, 2006).

6.2.1 Data collection

Hazard zoning

There are inherent problems when trying to identify the zoning of a flood event. As discussed earlier in Section 4.4, as much as possible the variables included in the model need to be as consistent as possible over that zone. In the case of the flooding in August 2004 it appears that there are two main risk zones; that of the village of Boscastle itself, and Crackington Haven a village around five miles North East of Boscastle. The zones have been selected using the properties and infrastructure that have been identified in post-flood investigations as having sustained damages (Barham, 2004; HR Wallingford, 2005b).

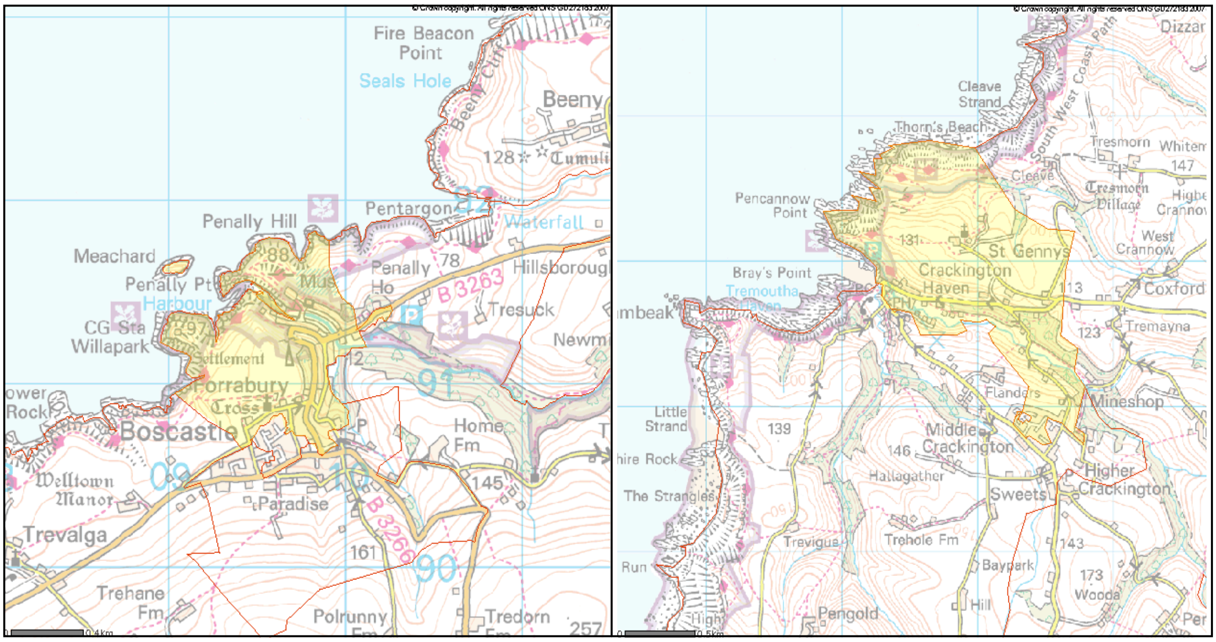
'At risk' population

The first major issue to emerge following the zoning of the area is to quantify the at-risk population (Nz). This is compounded in the case of Boscastle by the fact that the flooding occurred at the height of the tourist season and therefore there were many visitors to the local area and to the village itself on that day. The Environment Agency (2005c) states that the visitors' car park with 170 spaces was almost full at 3pm that afternoon only 45 minutes before the same car park began to flood. Therefore, deciding upon a population at risk during this event is problematic. Four different figures have been input into the model for this flood event. The first has been calculated by finding the resident population in the area from 2001 census statistics and to use this as a figure for N(z): i.e. the population at risk (although as stated below there are still area definition problems using this method).

The second method is similar to that adopted by HR Wallingford (2005a) when modelling the Carlisle 2005 flood event. The number of affected properties within the flood risk zone was calculated and then multiplied by the average people per household figure stated within ward statistics in the last census. A third method involved taking the estimated resident population and adding 340 to this figure. The figure of 340 has been calculated by assuming that each of the approximately 170 cars in the visitor car park that day transported two visitors to the area. The fourth figure used is a population value of 1000 which is a figure that has been estimated by the North Cornwall District Council (2004; p9): “Around 1000 residents and visitors are believed to have been affected in this devastating event.”

There is little documented evidence about visitors to the Crackington Haven area on the 16th August 2004; therefore this risk zone only has two different values for at-risk population. The first is directly derived from the 2001 census output area and is 212. The second is derived similarly to Boscastle from the number of buildings affected by flooding. Both Boscastle and Crackington Haven are located within the statistical ward of Valency and from the 2001 Census Neighbourhood Statistics this has an average number of 2.24 people per household. Therefore, for the Crackington Haven risk zone it was reported that 15 properties were affected by the flooding so if we assume that there were 2.24 people resident within these properties the N(z) for this risk zone would be 34. Similarly, Boscastle had 125 properties affected and therefore a population at risk of 280 is calculated.

Linking the population data from the 2001 census to the risk zone from the flooding event is problematic as the designated zones for census statistics are of course based on geographical and political boundaries, rather than reflecting any aspect of the physical environment. It has therefore been necessary to select which Census output area best reflects the risk zones from the August 2004 flood. In the case of Boscastle, UK Census output area 15UEHB004 was selected and for Crackington output area 15UEHB007 was used. Figure 6.2 illustrates these output areas.



Boscastle census output area | Crackington Haven census output area

Figure 6.2: Census output areas used to provide the population at risk and other people characteristics

Source: Crown Copyright accessed from the 2001 Census Neighbourhood Statistics Available http://neighbourhood.statistics.gov.uk/ Accessed 09/08/07.

People Vulnerability characteristics

The 2001 Census Statistics collected by UK National Statistics provide a number of different measures that could be used to fulfil the requirement of gaining "the percentage of all residents suffering from a long-term illness" (HR Wallingford, 2005a; p18). There are two categories of particular interest. The first category is that of *Limiting long-term illness* (UV22) which offers a proportion of the population with the following characteristics "A limiting long-term illness covers any long-term illness, health problem or disability that limits daily activities or work" (Office of National Statistics, 2001a). The second category is that of *General Heath* which offers categories of *Good health, Fairly good health* and *Not good health.* The category of interest *Not good health* is defined as "All people usually resident in the area at the time of the 2001 Census, who described their general health in the 12 months before Census day as 'Not good'" (Office of National Statistics, 2001b). The figures for each of these variables can be seen for both risk areas in Table 6.1.

Temporal differences are another consideration that must be mentioned with regard to the census statistics. The census data is only a snapshot of information (taken on the 29th April 2001). It is also only relevant for those considered to be "usual residents" and therefore there may be some inaccuracies in the count.

A further limitation of the use of these variables to represent the figure of population above the age of 75 years and the proportion of the 'at risk' population that have a long-term illness is that these census figures do not necessarily reflect the same demographic characteristics of the visiting population, however for the purposes of the modelling this assumption is required. This issue and its implications for the *Risk to People* modelling results will be discussed further in Section 7. Despite a number of problems and limitations involved when using census data of this kind, it is the best data that is available for these areas. Although there are problems with the data, and these problems need to be considered, they should not entirely preclude the use of the data.

Flood characteristics

As discussed in Section 4.4, assigning values to the physical characteristics of the flooding such as the depth or the velocity is very difficult, as these will vary considerably over the period of the flooding and across the risk zone. HR Wallingford (2005b) states that there were no direct measurements of the velocity of the flooding, though from observations of debris flow their subsequent simulations of velocity appear to be valid. Simulated velocities were calculated for different areas of the channel in Boscastle and it was stated that "the velocity in the main river channel is approximately 3 m/s. The kinematic wave speed of a flood wave in a natural channel is approximately 1.3 times the water velocity and so will be around 4 m/s" (HR Wallingford, 2005b; p127). The Environment Agency (2005b; p1) have also adopted the figure of 4m/s for the velocity of the event. The Crackington Haven event was observed to have a lower in-channel flood velocity. The post-flood analysis reported that the velocity in the main river channel is approximately 2 m/s by indicating that "if the kinematic wave speed of a flood wave in a natural channel is approximately 1.3 times the water velocity it will be around 3 m/s" (HR Wallingford, 2005b; p127). As these are the main channel velocities the model was also run with values that are lower than these figures as the water dissipates on to the floodplain. Therefore, the Boscastle modelling will be undertaken with velocities of 4 m/s, 2.5 m/s and 1 m/s and the Crackington Haven model with 3 m/s, 2 m/s and 0.75 m/s.

Similar to flood velocity, flood depths will vary over both temporal and spatial scales. An analysis of the damage to properties indicated that most buildings suffered floods more than 1m deep (Environment Agency, 2005c) in Crackington Haven although the actual depths varied from 0.49m to 1.89m (HR Wallingford, 2005b; p157 and Appendix 9). A depth of 1 metre will be used to model the predicted deaths in the Crackington Haven risk zone. In the Boscastle area flood trash line data recorded after the event ranged from 0.1m to 2.9m in height. Because of this variability three figures have been selected for modelling, 1m (a lower value), 1.66m (which is the mean of all of the damage depths from Boscastle properties) and 2.5m (a high value).

Table 6.1: Variables for application to the Risk to People Methodology

Model Variable	**Boscastle Risk Zone**	**Crackington Haven Risk Zone**	**Data quality and uncertainty**
POPULATION AT RISK			
Number of people affected in the area(s)/zones	**240** (2001 Census output area) **280** (Product of the number of properties and the average number of people per property) **580** (2001 Census output area plus estimated visitors from car numbers) **1000** (estimated by North Cornwall District Council, 2004)	**34** (Product of the number of properties and the average number of people per property) **212** (2001 Census output area)	Office of National Statistics (2001c) Neighbourhood Area Statistics (available from http://www.neighbourhood.statistics.gov.uk/dissemination/) Car information from Environment Agency (2005c) North Cornwall District Council (2004)
HAZARD RATING			
Depth	1m 1.66m 2.5m	1m	Environment Agency (2005b) HR Wallingford (2005b)
Velocity	4m/s 2.5 m/s 1m/s	3m/s 2m/s 0.75 m/s	Environment Agency (2005b) HR Wallingford (2005b)
Debris content	1	1	Environment Agency (2005b) HR Wallingford (2005b)
AREA CHARACTERISTICS			
Flood warning systems	3	3	Environment Agency (2005c)
Type of buildings	2	2	Environment Agency (2005c), HR Wallingford (2005b) and from photographs of the area
Rate of rise/speed of onset	2	2	Environment Agency (2005c) and HR Wallingford (2005b)
PEOPLE CHARACTERISTICS			
Age 75+	10%	14%	2001 Census Area Statistics (available from http://www.neighbourhood.statistics.gov.uk/dissemination/)
Health status (% of the population) • Limiting long-term illness • Not Good Heath	16% 5.98%	25% 13.21%	2001 Census Area Statistics (available from http://www.neighbourhood.statistics.gov.uk/dissemination/)
***RISK TO PEOPLE* OUTCOMES**			
Number of deaths	Zero		HR Wallingford (2005b) SW Resilience Forum (2006)
Number of seriously injured	Zero		HR Wallingford (2005b) SW Resilience Forum (2006)
Number of minor injuries	Reports vary from 1 broken thumb to 8 minor injuries		(North Cornwall District Council, 2005) SW resilience Forum (2006)

Both Crackington Haven and Boscastle experienced significant levels of debris within the water including silt, trees (and branches), stones and cars (Environment Agency, 2005b; HR Wallingford, 2005b). Therefore, both risk zones have been assigned a debris factor of 1. Evidence of this can be seen in the photographs in Figures 6.3 and 6.4.

Area vulnerability characteristics

The variables from the three different characteristics of Area Vulnerability have been assigned again from information presented in the reports mentioned above. A value of 3 has been assigned to the 'Flood Warning' category since there was really no effective flood warning prior to the flood event. Both Boscastle and Crackington Haven risk zones have a mix of residential and commercial properties and a variety of property types. They both have therefore been categorised as being a "typical residential" area and therefore assigned a value of 2 for 'Nature of Area.' The final category of speed of onset has been assigned a value of 2 as the flood waters rose over a matter of hours rather than minutes, despite there being sharp increases in the water depth during the flood.

The quality of the data input into the model is integral to the quality of the estimations and the results produced and, as Section 6.3 illustrates, the modelling results vary considerably depending upon the data input. However, the results do provide examples of the risks to people under different circumstances even if the estimates are what might have occurred in the worst case scenarios.

Figure 6.3: Centre of Boscastle village during flood.

(© David Flower[7])

[7] Photograph have been taken from ICDDS (2007)

Figure 6.4: Example of debris moved by the floods in Boscastle event

(© David Flower[8])

6.3 Risk to People modelling results

The data collected from secondary sources were input using the *Risk to People* methodology. To highlight the issues surrounding the selection of specific data different values have been input and the model run a number of times to highlight the differences in the resulting deaths that are predicted. For the Boscastle risk zone the modelling was completed in 72 runs to account for all of the possible combinations of variables and for the Crackington Risk zone 12 modelling runs were completed. The full analysis can be seen in Tables 6.3 and 6.4. The analyses show that the estimates of predicted injuries and deaths vary greatly depending on the different values entered for the variables. Table 6.2 provides a breakdown of the model outputs including the averages of the model predictions and the range of values presented.

Table 6.2: Modelling output statistics

	Boscastle risk zone	**Crackington Haven risk zone**
Range of Predicted Deaths	0.67 to 109.2	0.13 to 4.69
Average (mean) Predicted Deaths	14.30	1.43
Average (median) Predicted Deaths	7.73	0.78
Range of Predicted Injuries	13.42 to 445.9	2.91 to 52.09
Average (mean) Predicted Injuries	95.03	19.48
Average (median) Predicted Injuries	72.52	13.26
Estimated % of the population that would have died[9] (range)	0.3% to 11%	0.39% to 2.2%

[8] Photographs have been taken from ICDDS (2007)

[9] Note that this has been calculated by looking at the predicted number of deaths and dividing by the estimated population [N(z)] for that model run.

Table 6.3: Application of the Risk to the Boscastle risk zone

Hazard Zone	Population at risk N(z)	FLOOD CHARACTERISTICS				AREA CHARACTERISTICS				PEOPLE CHARACTERISTICS			Predicted Injuries	Predicted Deaths
		Depth	Velocity	Debris Factor	Hazard Rating	Flood warning	Nature of the area	Speed of onset	Area Vulnerability	% over 75 years	% with long term illness	People Vulnerability		
Boscastle 1	240	1	1	1	2.5	3	2	2	7	10	5.98	15.98	13.4232	0.67116
Boscastle 2	240	1	2.5	1	4	3	2	2	7	10	5.98	15.98	21.47712	1.7181696
Boscastle 3	240	1	4	1	5.5	3	2	2	7	10	5.98	15.98	29.53104	3.2484144
Boscastle 4	240	1.66	1	1	3.49	3	2	2	7	10	5.98	15.98	18.738787	1.3079673
Boscastle 5	240	1.66	2.5	1	5.98	3	2	2	7	10	5.98	15.98	32.108294	3.840152
Boscastle 6	240	1.66	4	1	8.47	3	2	2	7	10	5.98	15.98	45.477802	7.7039396
Boscastle 7	240	2.5	1	1	4.75	3	2	2	7	10	5.98	15.98	25.50408	2.4228876
Boscastle 8	240	2.5	2.5	1	8.5	3	2	2	7	10	5.98	15.98	45.63888	7.7586096
Boscastle 9	240	2.5	4	1	12.25	3	2	2	7	10	5.98	15.98	65.77368	16.114552
Boscastle 10	240	1	1	1	2.5	3	2	2	7	10	16	26	21.84	1.092
Boscastle 11	240	1	2.5	1	4	3	2	2	7	10	16	26	34.944	2.79552
Boscastle 12	240	1	4	1	5.5	3	2	2	7	10	16	26	48.048	5.28528
Boscastle 13	240	1.66	1	1	3.49	3	2	2	7	10	16	26	30.48864	2.1281071
Boscastle 14	240	1.66	2.5	1	5.98	3	2	2	7	10	16	26	52.24128	6.2480571
Boscastle 15	240	1.66	4	1	8.47	3	2	2	7	10	16	26	73.99392	12.53457
Boscastle 16	240	2.5	1	1	4.75	3	2	2	7	10	16	26	41.496	3.94212
Boscastle 17	240	2.5	2.5	1	8.5	3	2	2	7	10	16	26	74.256	12.62352
Boscastle 18	240	2.5	4	1	12.25	3	2	2	7	10	16	26	107.016	26.21892
Boscastle 19	280	1	1	1	2.5	3	2	2	7	10	5.98	15.98	15.6604	0.78302
Boscastle 20	280	1	2.5	1	4	3	2	2	7	10	5.98	15.98	25.05664	2.0045312
Boscastle 21	280	1	4	1	5.5	3	2	2	7	10	5.98	15.98	34.45288	3.7898168
Boscastle 22	280	1.66	1	1	3.49	3	2	2	7	10	5.98	15.98	21.861918	1.5259619
Boscastle 23	280	1.66	2.5	1	5.98	3	2	2	7	10	5.98	15.98	37.459677	4.4801773
Boscastle 24	280	1.66	4	1	8.47	3	2	2	7	10	5.98	15.98	53.057435	8.9879295
Boscastle 25	280	2.5	1	1	4.75	3	2	2	7	10	5.98	15.98	29.75476	2.8267022
Boscastle 26	280	2.5	2.5	1	8.5	3	2	2	7	10	5.98	15.98	53.24536	9.0517112
Boscastle 27	280	2.5	4	1	12.25	3	2	2	7	10	5.98	15.98	76.73596	18.80031
Boscastle 28	280	1	1	1	2.5	3	2	2	7	10	16	26	25.48	1.274
Boscastle 29	280	1	2.5	1	4	3	2	2	7	10	16	26	40.768	3.26144
Boscastle 30	280	1	4	1	5.5	3	2	2	7	10	16	26	56.056	6.16616
Boscastle 31	280	1.66	1	1	3.49	3	2	2	7	10	16	26	35.57008	2.4827916
Boscastle 32	280	1.66	2.5	1	5.98	3	2	2	7	10	16	26	60.94816	7.2893999
Boscastle 33	280	1.66	4	1	8.47	3	2	2	7	10	16	26	86.32624	14.623665
Boscastle 34	280	2.5	1	1	4.75	3	2	2	7	10	16	26	48.412	4.59914
Boscastle 35	280	2.5	2.5	1	8.5	3	2	2	7	10	16	26	86.632	14.72744
Boscastle 36	280	2.5	4	1	12.25	3	2	2	7	10	16	26	124.852	30.58874
Boscastle 37	580	1	1	1	2.5	3	2	2	7	10	5.98	15.98	32.4394	1.62197
Boscastle 38	580	1	2.5	1	4	3	2	2	7	10	5.98	15.98	51.90304	4.1522432
Boscastle 39	580	1	4	1	5.5	3	2	2	7	10	5.98	15.98	71.36668	7.8503348
Boscastle 40	580	1.66	1	1	3.49	3	2	2	7	10	5.98	15.98	45.285402	3.1609211
Boscastle 41	580	1.66	2.5	1	5.98	3	2	2	7	10	5.98	15.98	77.595045	9.2803674
Boscastle 42	580	1.66	4	1	8.47	3	2	2	7	10	5.98	15.98	109.90469	18.617854
Boscastle 43	580	2.5	1	1	4.75	3	2	2	7	10	5.98	15.98	61.63486	5.8553117
Boscastle 44	580	2.5	2.5	1	8.5	3	2	2	7	10	5.98	15.98	110.29396	18.749973
Boscastle 45	580	2.5	4	1	12.25	3	2	2	7	10	5.98	15.98	158.95306	38.9435
Boscastle 46	580	1	1	1	2.5	3	2	2	7	10	16	26	52.78	2.639
Boscastle 47	580	1	2.5	1	4	3	2	2	7	10	16	26	84.448	6.75584

Hazard Zone	Population at risk N(z)	FLOOD CHARACTERISTICS				AREA CHARACTERISTICS				PEOPLE CHARACTERISTICS			Predicted Injuries	Predicted Deaths
		Depth	Velocity	Debris Factor	Hazard Rating	Flood warning	Nature of the area	Speed of onset	Area Vulnerability	% over 75 years	% with long term illness	People Vulnerability		
Boscastle 48	580	1	4	1	5.5	3	2	2	7	10	16	26	116.116	12.77276
Boscastle 49	580	1.66	1	1	3.49	3	2	2	7	10	16	26	73.68088	5.1429254
Boscastle 50	580	1.66	2.5	1	5.98	3	2	2	7	10	16	26	126.24976	15.099471
Boscastle 51	580	1.66	4	1	8.47	3	2	2	7	10	16	26	178.81864	30.291878
Boscastle 52	580	2.5	1	1	4.75	3	2	2	7	10	16	26	100.282	9.52679
Boscastle 53	580	2.5	2.5	1	8.5	3	2	2	7	10	16	26	179.452	30.50684
Boscastle 54	580	2.5	4	1	12.25	3	2	2	7	10	16	26	258.622	63.36239
Boscastle 55	1000	1	1	1	2.5	3	2	2	7	10	5.98	15.98	55.93	2.7965
Boscastle 56	1000	1	2.5	1	4	3	2	2	7	10	5.98	15.98	89.488	7.15904
Boscastle 57	1000	1	4	1	5.5	3	2	2	7	10	5.98	15.98	123.046	13.53506
Boscastle 58	1000	1.66	1	1	3.49	3	2	2	7	10	5.98	15.98	78.07828	5.4498639
Boscastle 59	1000	1.66	2.5	1	5.98	3	2	2	7	10	5.98	15.98	133.78456	16.000633
Boscastle 60	1000	1.66	4	1	8.47	3	2	2	7	10	5.98	15.98	189.49084	32.099748
Boscastle 61	1000	2.5	1	1	4.75	3	2	2	7	10	5.98	15.98	106.267	10.095365
Boscastle 62	1000	2.5	2.5	1	8.5	3	2	2	7	10	5.98	15.98	190.162	32.32754
Boscastle 63	1000	2.5	4	1	12.25	3	2	2	7	10	5.98	15.98	274.057	67.143965
Boscastle 64	1000	1	1	1	2.5	3	2	2	7	10	16	26	91	4.55
Boscastle 65	1000	1	2.5	1	4	3	2	2	7	10	16	26	145.6	11.648
Boscastle 66	1000	1	4	1	5.5	3	2	2	7	10	16	26	200.2	22.022
Boscastle 67	1000	1.66	1	1	3.49	3	2	2	7	10	16	26	127.036	8.8671128
Boscastle 68	1000	1.66	2.5	1	5.98	3	2	2	7	10	16	26	217.672	26.033571
Boscastle 69	1000	1.66	4	1	8.47	3	2	2	7	10	16	26	308.308	52.227375
Boscastle 70	1000	2.5	1	1	4.75	3	2	2	7	10	16	26	172.9	16.4255
Boscastle 71	1000	2.5	2.5	1	8.5	3	2	2	7	10	16	26	309.4	52.598
Boscastle 72	1000	2.5	4	1	12.25	3	2	2	7	10	16	26	445.9	109.2455

Table 6.4: Application of the Risk to the Crackington Haven risk zone

Hazard Zone	Population at risk N(z)	FLOOD CHARACTERISTICS				AREA CHARACTERISTICS				PEOPLE CHARACTERISTICS			Predicted Injuries	Predicted Deaths
		Depth	Velocity	Debris Factor	Hazard Rating	Flood warning	Nature of the area	Speed of onset	Area Vulnerability	% over 75 years	% with long term illness	People Vulnerability		
Crackington Haven 1	34	1	0.75	1	2.25	3	2	2	7	14	13.21	27.21	2.914191	0.1311386
Crackington Haven 2	34	1	2	1	3.5	3	2	2	7	14	13.21	27.21	4.533186	0.317323
Crackington Haven 3	34	1	3	1	4.5	3	2	2	7	14	13.21	27.21	5.828382	0.5245544
Crackington Haven 4	34	1	0.75	1	2.25	3	2	2	7	14	25	39	4.1769	0.1879605
Crackington Haven 5	34	1	2	1	3.5	3	2	2	7	14	25	39	6.4974	0.454818
Crackington Haven 6	34	1	3	1	4.5	3	2	2	7	14	25	39	8.3538	0.751842
Crackington Haven 7	212	1	0.75	1	2.25	3	2	2	7	14	13.21	27.21	18.170838	0.8176877
Crackington Haven 8	212	1	2	1	3.5	3	2	2	7	14	13.21	27.21	28.265748	1.9786024
Crackington Haven 9	212	1	3	1	4.5	3	2	2	7	14	13.21	27.21	36.341676	3.2707508
Crackington Haven 10	212	1	0.75	1	2.25	3	2	2	7	14	25	39	26.0442	1.171989
Crackington Haven 11	212	1	2	1	3.5	3	2	2	7	14	25	39	40.5132	2.835924
Crackington Haven 12	212	1	3	1	4.5	3	2	2	7	14	25	39	52.0884	4.687956

As was reported in Table 6.1 there were no reported fatalities from either the Boscastle or the Crackington Haven risk zones and injuries caused from the flooding event were few and minor in nature. Therefore, the model's performance varies dramatically depending upon which values are used. This case study therefore illustrates the sensitivity of the model to the input of key variables (as described previously in Section 4.4) and highlights the difficult nature of estimating these values within a specific risk zone. However, it is possible to argue that the maximum values predicted for the two risk zones (estimated number of deaths from 109 for Boscastle and five for Crackington Haven) could be taken as the worst-case scenario predictions for the flooding of August 2004. If a more reasonable and realistic estimate is adopted (in this case the median) then the numbers who perished would be reduced to 8 for Boscastle and 1 in Crackington Haven. Of course even these values are over-estimating the actual fatalities for the event and the numbers of injuries even more so.

The predicted values modelled for Crackington Haven appear however to be more reasonable and closer to what actually occurred during the event. This is likely to be due to the fact that this case (and particularly when the estimate for population at risk is taken to be 34) is a much smaller risk zone to that of Boscastle and the event was smaller in magnitude.

The events surrounding the Boscastle risk zone are more interesting however, both for the application of the *Risk to People* methodology and for the refinement of this approach. The Boscastle event has been compared (Environment Agency, 2005b) to the Lynmouth event which took place 52 years to the day before the flooding of August 2004. Therefore it is interesting to contrast the results of the modelling of this event with the modelling undertaken within the original *Risk to People* methodology. The percentage of the population who died (or who were predicted to die) has been presented so that the two flood events can be contrasted. These results are presented in Table 6.5.

Table 6.5: Proportion of the 'at risk' population who died (or percentage predicted to have died)

Zone	**Percentage of the 'at risk' population who were killed**
Lynmouth Actual	8.5%
Lynmouth Predicted	5.75%
Boscastle Predicted	0.3% to 11% (mean = 3%)

Although the Boscastle modelling output produces a range of predicted percentages, the range of fatalities is comparable to the actual fatalities which occurred from the similar flood in Lynmouth. Therefore, although the event is clearly over-predicting the number of people that died, since there were no fatalities in Boscastle, it could be stated that under different circumstances the number of fatalities from a similar event might be higher. Therefore, the circumstances surrounding the Boscastle event will be examined to investigate why there were low numbers of injuries and fatalities and what lessons can be learned to inform and refine the *Risk to People* model.

6.4 Analysis of the circumstances surrounding the event

If the original *Risk to People* model is applied to the Boscastle case study it emphasises the fact that the circumstances leading to loss of life are very complex and there are many factors which may influence whether any fatalities occur. The low numbers of injuries and the fact that no one was killed in the flood, and in particular in the village of Boscastle where flood waters were at their most ferocious, has been described as a miracle (Rowe, 2004). As well as some good fortune being evident during the flood it is also the case that there were a number of different aspects which meant that no-one lost their lives in the flooding and injuries were minimised.

6.4.1 Timing of the flood

There was no official warning for the Boscastle flooding event from the authorities (reflected in the model with a Flood warning score of 3) however, a number of factors were present which meant that people were not completely unaware of the rising water levels. The first aspect that was fortuitous was the timing of the flood event itself. The flooding occurred during daylight hours and therefore it was possible for a number of people in the area to see the rain and witness the waters rising, "Eyewitnesses at both Boscastle and Crackington Haven described water levels rising in only minutes or even seconds" (Environment Agency, 2005c, p13).

The rain began falling at lunchtime and was worsening by early afternoon; this meant that some visitors had already left the area to get out of the elements before the peak of the flood. Rowe (2004) argues that in August there would often have been many walkers hiking on paths around the village and close to the Valency, however he states that "the deluge must have driven them (the walkers) away before the flood peaked" (p60). Others were reported to have taken shelter within their vehicles located at the top of the village (Rowe, 2004). The flooding of the car park early in the Boscastle event meant that some visitors were able to observe the flood waters before they became more severe and thus to move from the area. Despite this, the rapid onset did still mean that others became trapped within their cars in the car park and subsequently needed to be rescued.

In addition to people actually witnessing the rise in water levels and the presence of floodwaters in the village for themselves, Rowe (2004) also describes how many members of the local community phoned friends, family and neighbours in the town and in neighbouring areas warning them of the danger. Despite no effective official flood warning prior to the flood event, the reaction of the authorities and members of the public, once it was realised that flooding was occurring and that lives were threatened, was extensive. Had the flood occurred at night it is possible that lives would have been lost, as rescue by helicopter would have been more difficult.

6.4.2 'Non-official' rescuers

The presence of visitors and tourists in an area during flooding might be considered to be problematic due to the fact that they are likely to have a lower understanding of the flood risk and what actions to take at the time of an event. However, this was not the case with this event as among the local population awareness of the flood risk was generally low and the actions of many visitors was considered to be one of the contributing factors to successful rescue of people from the floodwaters. Many people (mainly young to middle-aged males) were reported to have returned to areas of the village where people required rescuing after ensuring that their own families were safely away from the danger areas; this situation can be seen in Figure 6.5 (Rowe, 2004). In addition, there is some anecdotal evidence to suggest that the presence of surfers (i.e. mainly young, able-bodied males) who were present in Boscastle that day were fundamental to the assistance of those less able members of the Boscastle community to escape from the flood waters (B.Watts, Environment Agency, pers. comm.). These heroic actions were not just undertaken by visiting members of the public, members of the local community were also involved in not only saving themselves from the floodwaters, but also assisting others to safety (Rowe, 2004; Environment Agency, 2005c; South West Resilience Forum, 2006).

6.4.3 Official search and rescue effort

Following the realisation of the seriousness of the flooding by helicopter pilots who were initially sent to Boscastle, a major incident was declared by HM Coastguard at 16:35 who called for further air support (South West Resilience Forum, 2006). This resulted in the dispatch of a further five military helicopters and a Coastguard helicopter, who in total airlifted 97 people from Boscastle, many of whom were stranded on the roofs of buildings (South West Resilience Forum, 2006). One of these air rescues can be seen in Figure 6.6. Additionally, firefighters were dispatched to the area and assisted in the rescue of around another 50 people on the ground (South West Resilience Forum, 2006). The post-flooding debriefing report also states that three Royal National Lifeboat Institution (RNLI) lifeboats were also dispatched to the harbour in anticipation that victims would need to be rescued from the sea.

Figure 6.5: Members of the public rescuing others from the floodwaters in Boscastle
(© David Flower[10])

Figure 6.6: Helicopter rescuing those caught up in the flood waters.
(© David Flower[10])

[10] Photographs have been taken from ICDDS (2007)

Although the level of search and rescue activity was extensive, and to a great degree can be argued as being a significant factor in the prevention of fatalities and serious injury, the level of response (i.e. the number of helicopters in the area available to respond) was considered to be "fortunate" (South West Resilience Forum, 2006; p36). This was due to the fact that a number of helicopters were in the area due to a local military training exercise and therefore were close enough to Boscastle to respond. It is unclear however, whether the presence of so many helicopters (the seven helicopters that undertook the rescuing of people, the assistance of the Cornwall Air Ambulance, plus a Chinook heavy lift helicopter put on standby and sent from Hampshire to a closer airfield) actually led to the success of the mission, as the topography of the village meant that only one helicopter could enter the village and undertake rescuing at any one time and the helicopters were having to queue in order to enter the vicinity. Therefore, a similar number of people might have been able to be rescued by fewer helicopters.

6.5 Implications for the Risk to People methodology

The Boscastle and Crackington Haven risk zones are examples whereby the risks from flooding to loss of life were extremely severe, yet no deaths resulted. The range of fatalities predicted by the model varied from 0.67 to 109.2 for Boscastle and from 0.13 to 4.69 for Crackington Haven, depending upon the values input. The study is a useful application for the *Risk to People* methodology as not only does it highlight the significance of the data input to the model, and the fact that a range of values might be a more appropriate output rather than an absolute prediction of deaths, but it also highlights factors that the current methodology does not really consider. Of course it is understood that any method or model of this nature can never fully and perfectly model what is occurring in each and every flood event, but it does illustrate that factors such as the timing of the flood, unofficial warning systems and evacuation are major components that are missing from the current approach. These will also be more important when considering the types of flood events which are more common in Continental Europe; that is floods that can be deep, have a rapid onset, high velocity and where evacuation is a more common and necessary response.

7. European calibration of the UK *Risk to People* Model

7.1 Introduction

In the following sections the general applicability of the *Risk to People* model for Continental European flood events is evaluated. A sensitivity analysis was carried out on the European data colleted and the model results for the European case studies are described and discussed.

7.2 Sensitivity analysis

In order to show how much influence each component of the model equation has on the outcomes, the attributes of each baseline variable were changed in turn, while the other variables were held constant. Carlisle Zone B was chosen as the baseline for the analysis since it is arguably illustrative of a 'typical' UK flood. The summarised results are shown in Tables 7.1 through 7.3.

First, the value for Nz was altered to ensure that the size of the population at risk affected the model results in a predictable way. This is confirmed in Table 7.1 when doubling and then tripling the value of Nz has the effect of doubling and tripling the predicted fatalities.

Table 7.1: Sensitivity Analysis – Nz and Hazard Rating

	Nz	Depth	Velocity	Debris Factor	HR score	Predicted injuries	Predicted fatalities	% change
Carlisle zone B	**420**	**1.0**	**0.5**	**0.0**	**1**	**12**	**0.24**	
Population x 2	840	1.0	0.5	0.0	1	24	0.48	100
Population x 3	1,260	1.0	0.5	0.0	1	36	0.72	200
Change depth to 2m	420	2.0	0.5	0.0	2	24	0.95	300
Change depth to 2.5m	420	2.5	0.5	0.0	2.5	30	1.49	525
Change depth to 3m	420	3.0	0.5	0.0	3	36	2.14	800
Change velocity to 1m/s	420	1.0	1.0	0.0	1.5	18	0.53	125
Change velocity to 1.5m/s	420	1.0	1.5	0.0	2	24	0.95	300
Change velocity to 2m/s	420	1.0	2.0	0.0	2.5	30	1.49	525
Change DF to 0.5	420	1.0	0.5	0.5	1.5	18	0.53	125
Change DF to 1	420	1.0	0.5	1.0	2	24	0.95	300

It can be seen from Table 7.1 that changes to the Hazard Rating can have a dramatic effect on the model results. Doubling depth from 1m to 2m led to a 300% increase in predicted deaths, for instance, as did changing velocity from 0.5 to 1.5 m/s.

According to the analysis, the Area Vulnerability component of the model has the least effect on the model outcomes. Changing warning characteristics, speed of onset, and nature of area on an individual basis has little effect on injuries and fatalities, as shown in Table 7.2. Changing all of the characteristics to maximum vulnerability (giving an AV score of 9) increases injuries by 80%, which is a much weaker effect than changing the HR variables.

Table 7.2: Sensitivity Analysis – Area Vulnerability

	Flood Warning	Speed of onset	Nature of area	AV score	Predicted injuries	Predicted fatalities	% change
Carlisle zone B	**2**	**1**	**2**	**5**	**12**	**0.24**	
Change warnings to 3	3	1	2	6	14	0.29	20
Change speed of onset to 3	2	3	2	7	17	0.33	40
Change nature of area to 3	2	1	3	6	14	0.29	20
Change all to 3	3	3	3	9	21	0.43	80

The small effect of AV on model outcomes is partly a function of the structure of the formula, but there is also an extremely limited range of values (1 – 3) that can be selected for each component of Area Vulnerability. AV is also the only one of the three categories of information that is wholly based on scores, rather than actual values. Certainly it seems strange that critical factors such as speed of onset, land use, and effective flood warnings are constrained in this way.

The current model is hugely sensitive to people vulnerability as demonstrated in Table 7.3. Changing People Vulnerability to 50% has a dramatic effect on injuries. This is because injuries are calculated as a function of 'people at risk' multiplied by 'people vulnerability'; changing PV to 0% obviously therefore eliminates injuries and deaths altogether.

Table 7.3: Sensitivity Analysis – People Vulnerability

	Nz	HR	AV	PV (%)	Predicted injuries	Predicted fatalities	% change
Carlisle zone b	**420**	**1.0**	**5**	**28**	**12**	**0.24**	
change PV to 100%	420	1.0	5	100	42	0.84	253
change PV to 50%	420	1.0	5	50	21	0.42	77
change PV to 0%	420	1.0	5	0	0	0.00	-100
change all high with PV 25%	420	14.5	9	25	274	79.47	33,332
change all low with PV 25%	420	0.5	3	25	3	0.03	-87
change all high with PV 50%	420	14.5	9	50	548	158.95	66,764
change all low with PV 50%	420	0.5	3	50	6	0.06	-73
change all high with PV 100%	420	14.5	9	100	1,096	317.90	133,628
change all low with PV 100%	420	0.5	3	100	13	0.13	-47

High PV values can trigger model instability if all other variables are extreme, in that more people are injured than are in the Hazard Zone. This issue was further explored at the bottom of Table 7.3, where the extreme and mild HR and AV values are tested against different values of PV (the HR of 14.5 was selected from the Lynmouth event, which is the most severe UK example for which data is available). The cells shaded grey show where predicted injuries exceed the at-risk population. Although it is acknowledged that a PV value of 100% is extremely unlikely, a value of 50% is rather more plausible. In the Continental European context, the PV does not have to be as high as this because the greater HR values help to trigger instability at lower values of PV; this issue is explored further in Section 7.4.2.

7.2.1 Summary

Changes to the Hazard Rating component of the model have dramatic, yet plausible, results. Changes to the Area Vulnerability component have a much less pronounced effect on the model outputs, largely because of the limited range of values that can be selected. The model is hugely sensitive to People Vulnerability because of its function as a multiplier in the final calculation of injuries. The sensitivity analysis also revealed a structural flaw in the model in that when all variables are high (by UK standards) and PV is equal to or greater than 50 per cent, the model predicts that there are actually more people injured than are resident in the hazard zone.

7.3 Model application

7.3.1 UK flood events

The model results for the UK are presented in Table 7.4. Note that all Tables 7.4 through 7.6 are summaries of the complete model, the full model results can be seen in Appendix C. It can be seen that when applied to the Carlisle floods of January 2005 (the only non-calibration event) the model generates a result that is consistent with reality, 1.8 deaths predicted, and 3 deaths occurring. The correlation coefficient (predicted deaths against actual deaths) is equivalent to unity and is significant at the 0.01 level. This correlation is obviously influenced by the inclusion of the calibration events, around which the model was designed, and the small size of the sample but there is a dearth of flood-generated fatalities in the UK for model testing. It should also be noted that, while the model parameters are broken down into zones, the actual fatality figures in their original form are not, so the correlation is based on aggregated predicted deaths. Further research revealed a breakdown of the Lynmouth deaths by area (Delderfield, 1981). The results, shown in Table 7.5, show a slightly weaker correlation of 0.97. A nonparametric correlation (Spearman's rho) was also applied to this dataset, the result was a coefficient of 0.82, significant at the 0.05 level. It should be noted that the sample sizes are very small, 4 and 6 pairs of cases respectively. The small sample size affects the reliability of the statistical tests so more data is needed to evaluate the utility of the *Risk to People* model with respect to the UK.

Table 7.4: Summary of Risk to People Model inputs and results compared with actual fatalities (Lynmouth results aggregated)

Hazard Zone	Nz	HR	Predicted Injuries	Predicted Deaths	Total Predicted Deaths	Actual Deaths
Gowdall*	250	1.00	5.0	0.1	0.1	0
Norwich 1*	500	2.25	34.8	1.6	2.4	4
Norwich 2*	2,500	0.70	54.2	0.8		
Lynmouth 1*	100	14.50	59.9	17.4	24.2	34
Lynmouth 2*	100	8.00	33.0	5.3		
Lynmouth 3*	200	3.00	24.8	1.5		
Carlisle A	640	1.50	5.4	0.2	1.8	3
Carlisle B	420	1.00	11.9	0.2		
Carlisle C	135	1.50	4.6	0.1		
Carlisle D	888	1.50	35.8	1.1		
Carlisle E	1,530	0.50	20.6	0.2		
* Calibration events					Correlation coefficient 1.0 Significant at the 0.01 level	

Table 7.5: Summary of Risk to People Model inputs and results compared with actual fatalities (Lynmouth results disaggregated)

Hazard Zone	Nz	HR	Predicted Injuries	Predicted Deaths	Total Predicted Deaths	Actual Deaths
Gowdall*	250	1.00	5.0	0.1	0.1	0
Norwich 1*	500	2.25	34.8	1.6	2.4	4
Norwich 2*	2,500	0.70	54.2	0.8		
Lynmouth 1*	100	14.50	59.9	17.4	17.4	28
Lynmouth 2*	100	8.00	33.0	5.3	5.3	3
Lynmouth 3*	200	3.00	24.8	1.5	1.5	3
Carlisle A	640	1.50	5.4	0.2	1.8	3
Carlisle B	420	1.00	11.9	0.2		
Carlisle C	135	1.50	4.6	0.1		
Carlisle D	888	1.50	35.8	1.1		
Carlisle E	1,530	0.50	20.6	0.2		
* Calibration events					Correlation coefficient 0.97 Significant at the 0.01 level	

7.3.2 Continental Europe flood events

When applied to the European case studies, the *Risk to People* model results can only be described as erratic, as Table 7.6 shows (note that this table is a summary of the model inputs and results, the full array of data can be seen in Appendix D). In most cases the model overestimates the number of deaths, and while some of these overestimates are moderate, such as La Farinera, Spain, others are huge, such as the Klodzko Town zone c. It is also clear from the table that the HR values of continental floods are significantly higher than those so far obtained in the UK.

There is no significant correlation (parametric or nonparametric) between the predicted and actual fatalities in the European case studies. In two cases the model underestimates the number of deaths. The Cambrils case study result (two deaths predicted, three occurred) appears to be a function of the very low PV score of 1 per cent. It is not clear why the Troubky case underestimates the number of deaths (2 deaths predicted, 9 occurred) although this could be due to incorrect zoning (the importance of correct zoning information is discussed elsewhere). The correct prediction for Fortezza of five fatalities is probably due to the small number of people in the hazard zone (estimated at 60) which offsets the high HR value of 39.

The Klodzko town (c) case study has an extremely high Hazard Rating. This is responsible for a gross distortion of the predicted injuries and fatalities values, revealing another structural flaw in the model in that more deaths than injuries are predicted. This issue is discussed further below under ‘Hazard Rating’.

7.4 Discussion

7.4.1 Model issues

It is important to note that the *Risk to People* model was developed under two major constraints. The first is that the model was specifically designed for floods in England and Wales; this means that, because there are so few flood fatalities in the UK as a whole, there were very few suitable events available for model development, calibration and testing. In addition to the project’s time and resource constraints, the other condition on the product was that its results had to be mappable; this restricted the type of data that could be used in the model to those with a locational element. Nevertheless, the model results for the UK case studies are reasonable estimates, despite the logical inconsistencies that have been identified in the formula. Unfortunately the model is less successful when applied to the Continental European case studies, and generally over-predicts the fatalities. This is partly because the high hazard ratings associated with floods in Continental Europe revealed a logical flaw in the model that simply did not apply at the comparatively low HR values obtained in the UK.

Table 7.6: Summary of Risks to People Model results compared to actual fatalities in Europe

Country	Flood event	Nz	HR	Predicted injuries	Predicted deaths	Actual deaths
Italy	Fella a	400	9.8	47	9	1
Italy	Fella b	500	11.5	58	13	1
Italy	Cassano Murge	20,000	17.5	4,263	1,492	7
Italy	Fortezza	60	39.0	7	5	5
Spain	Calonge	1,300	3.0	137	8	1
Spain	Cambrils	2,000	6.0	14	2	3
Spain	La Farinera	200	6.0	33	4	1
Spain	Magarola	300	47.5	160	152	4
Poland	Duszniki zdroj	120	43.0	66	57	7
Poland	Klodzko gmina	1,050	21.9	210	92	1
Poland	Klodzko town zone a	200	23.0	58	27	1
Poland	Klodzko town zone c	2,500	69.2	1,330	1,841	5
Poland	Miedzylesie	876	12.0	134	32	1
Poland	Stronie Slaskie	2,000	43.0	826	710	1
Czech R	Troubky	2,010	2.6	37	2	9
Czech R	Olomouc	28,200	2.8	384	22	2
Czech R	Otrokovice	19,000	3.9	389	31	1
France	Gard	230,510	49.0	121,986	119,546	23
Germany	Dresden	300	9.1	44	8	1

Hazard Rating

There appear to be several factors that render the model less reliable for predicting deaths in the European mainland compared to the UK. The rivers in England and Wales are comparatively small, for example the river Thames, one of England's largest rivers is 338 km long whilst the Elbe and Oder are 1,165 km and 912 km long respectively (http://worldatlas.com/webimage/countrys/euriv.htm). The average depth of flooding in the UK during the autumn 2000 flood events was around 0.3m while an inundation depth of 4m was reported during the River Elbe 2002 floods (DKKV, 2004). Flooding from relatively minor rivers can also be much more severe in continental Europe than in the UK because the upper catchments are often mountainous, which means that the speed of onset can be very rapid and debris content can be high. The Polish case studies, for example, are from a mountainous region where valleys are narrow, steep and rocky and flooding can be almost immediate (ARUP, 2006).

The hazard rating component of the *Risk to People* formula is therefore not appropriate for the large rivers of continental Europe. HR Wallingford (2005c) proposes that a hazard rating of greater than 2.5 represents 'extreme danger'. The HR values for the UK case studies range from 0.5 to 14.5, average 3.2; this is in stark contrast to the HR of the European case studies, which range in value from 2.6 to 69, averaging 22.9.

The formula for fatalities (Fatalities = 2*Injured*HR/100) is structurally flawed. Clearly, if the Hazard Rating is equal to 50, the number of predicted deaths will be equal to the number of predicted injuries. If HR exceeds 50, then the number of deaths will exceed the number of injuries. Whilst this is theoretically impossible according to the terms of the model (deaths calculated as a proportion of injuries) the structure of the formula makes this inevitable. This must have been apparent to the authors of the model, who must have (quite reasonably) assumed that the HR associated with flood events in England and Wales would never approach 50.

Area Vulnerability

As stated above, the AV component of the model has the weakest effect on model outcomes. It has been suggested (HR Wallingford, 2005a) that the AV should be split into two subcategories; one to express the physical features of the area, and another to express the effectiveness of risk mitigation measures. This latter score could be a negative number so that the greater the effectiveness, the smaller the AV score (HR Wallingford, 2005a). This in itself may be insufficient to take into account the influence of effective flood risk management because, while empirical observations suggest that effective flood mitigation measures, including spatial planning and emergency response can have a huge effect on flood deaths; AV has the smallest influence on model results. To include this information in the model would therefore require the structure of the formula to be altered, and would also possibly necessitate increasing the range of scores that could be used.

People Vulnerability

As mentioned above, PV is a key variable in the *Risk to People* model. With respect to the UK, the focus on PV may well be valid; flood events in the UK are comparatively moderate and one would expect fatalities to be concentrated among the elderly and infirm (although it should be noted that this did not seem to be the case in the UK floods of summer, 2007). By contrast, the large rivers and mountainous catchments of the European mainland are capable of generating floods of much greater severity, creating a situation whereby the young and fit are just as likely to be injured or killed as the old and ill. Indeed, where the ages of flood-victims are given in the European case studies, it seems that young (or at least non-elderly) people are just as likely to be killed as the elderly.

Again, this is not a simple matter to address. The current model calculates injuries as a function of people estimated to be at risk, multiplied by the percentage PV factor. PV therefore cannot simply be ‘amputated’ from the formula because that would give the result of many more injuries, and therefore deaths, than is presently the case.

7.4.2 Model instability

The sensitivity analysis demonstrated that higher HR and AV values lower the threshold at which PV causes instability. PV was modelled against different HR values in order to establish the lowest PV value (PVm) at which anomalous results occur. Two different AV scenarios were used, 9 (maximum vulnerability) and 6 (average vulnerability). The minimum HR values were set at the lowest value at which model breakdown occurs when PV is equal to 100 per cent. PV was then reduced to the lowest point where more injuries are predicted than people in the hazard zone. The maximum of 50 was chosen because it is the highest value that can be entered into the model before it generates more fatalities than injuries (another anomaly that is discussed elsewhere). The HR value of 14.5 is included because it is the highest HR score so far obtained in the UK.

When the AV score is 9, the model reaches instability point when HR is 6 and PV is equal to 93. When AV is 6, the corresponding HR value is 10 and PV is 84. Table 7.7 shows the range of HR values, along with the minimum PV value that causes the model to generate more injuries than people in the hazard zone (PVm) when the AV score is set at the maximum of 9.

Table 7.7: The minimum PV value that causes model instability (PVm) at different HR scores (AV maximum of 9)

People at risk	HR	PVm	Predicted number of injured	Predicted fatalities
420	6	93	422	51
420	10	56	423	85
420	14.5	39	428	124
420	20	28	423	169
420	30	19	431	259
420	40	14	423	339
420	50	12	454	454

When AV is set to the maximum value of 9, the model is unstable when PV is only 19% and HR is equal to 30. A Hazard Rating of 30 is not unreasonable in the European context and a PV of 19%, including elderly and infirm, is realistic. In England and Wales, for instance, 16% of the population are aged 65 and over (ONS, 2003). Table 7.8 shows when PVm is reached when the AV score is set at the median value of 6. The minimum PV value that causes model instability (PVm) at different HR scores for both AV values is displayed graphically in Figure 7.1.

At high HR scores, model instability can be triggered by relatively small PV values, particularly when AV is set at the maximum value of 9. In these circumstances model instability is caused when HR equals 40 and PV equals just 14 per cent.

Table 7.8: The minimum PV value that causes model instability (PVm) at different HR scores (AV average of 6)

People at risk	HR	PVm	Predicted number of injured	Predicted fatalities
420	10	84	423	85
420	14.5	58	424	123
420	20	42	423	169
420	30	28	423	254
420	40	21	423	339
420	50	17	428	428

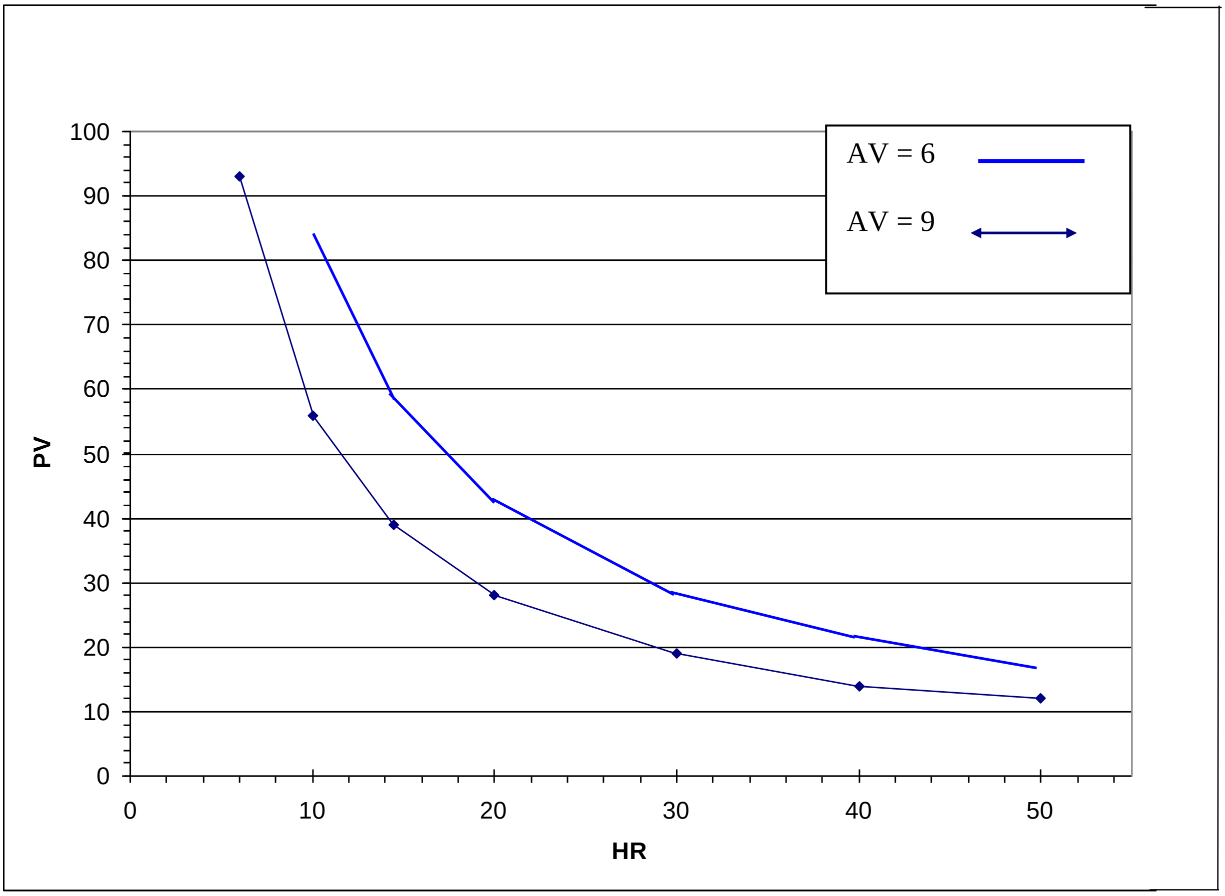


Figure 7.1: The minimum PV value that causes model instability (PVm) at different HR scores and different values of AV

7.4.3 Data issues and institutional arrangements

The original research underlying the model was restricted to variables that could be mapped. This precludes all sorts of information relevant to loss of life in flood events. Temporal information such as time of year is important because the temperature of floodwaters affects survival rates and seasonal variations also affect tourist/visitor numbers (see Section 2.3.1). Floods that occur at night tend to generate more injuries and/or fatalities than those that occur during daylight hours. The duration of the flood event is a further consideration. Human behaviour, in terms of what people are doing when a flood occurs, and what they do in response to the flood, is a significant factor in flood fatalities. None of these variables could be included because they are not spatial in nature. Finally, the role of chance, outlined above in Section 5.3.4 also needs to be recognised.

Zoning

Correct zoning is essential for estimating the number of people at risk. This naturally affects the model outcomes, as outlined in the sensitivity analysis. Zoning information is also vital for the HR element of the model, otherwise gross averages must be used. It is acknowledged that, while the *Risk to People* formula is simple, the associated data gathering requirements are not; different zones should be designated for different flood depths and velocities and, ideally, for different area and population characteristics. The different hazard zones identified by HR Wallingford (2003, 2005a) were based on distance from the river (see Figure 3.7). Whilst this may be appropriate for large, low-lying floodplains, it seems doubtful that distance from the river on its own can adequately capture differences in flood characteristics within small flashy catchments and/or catchments that are heavily urbanised. In these circumstances, the micro-effects of buildings and topography on flood velocities and depths would make accurate zoning extremely difficult.

Double counting

It has been noted that the PV elements (the old and the infirm) are not necessarily mutually exclusive and there is a risk of double-counting. Given the influence that PV has on the model results, it is important that this does not occur. The UK census gives age bands for most variables which allow users to identify the percentage population which is infirm, but not elderly. The quality and availability of census data across Europe is variable, but even assuming that every country had access to equivalent information, the problem remains that flood hazard zones rarely, if ever, correspond to census geography. Clearly, site-specific data gathering on these variables would be prohibitively time-consuming, except in zones where the population is very small, so ideally some sort of compromise must be made between local information and census/national estimates.

Transients

Two of the Spanish case studies, Botarell and Cagarel, could not be entered into the model because there were no resident 'at-risk' populations (Nz = 0). Nevertheless, seven fatalities did occur in these events although the people who died were transients. Such people are known to be at risk because they are unfamiliar with the area and may also have problems with the local language and would therefore have difficulty understanding warning signs such as road closures and diversions. All seven people who died in these two events had tried to cross a river by car. At present, there is no way of including transient populations within the model.

Reporting issues

The case studies contain very little information on the number of injuries incurred. This is perhaps not surprising since injuries are much less likely to be reported than deaths, and where injuries are reported, for instance to local hospitals and doctors, there is no guarantee that the injury would be recorded as flood-related and the information would therefore be harder to gather. The reporting of deaths, while more reliable than injuries, can also be less than perfect (see Sections 2.2 and 5.1).

Institutional arrangements

Institutional arrangements are an important factor affecting potential fatalities from a flood event, as highlighted in the Boscastle case study (Section 6). Mitigating actions such as rescue and evacuation are not considered by the *Risk to People* formula. Although development control is implicit in the 'Nature of Area' element of AV, and flood warnings are explicitly included in the AV score, the sensitivity analysis has demonstrated that AV has least effect on the model outcomes. The positive side of flooding from major rivers such as the Danube is that they tend to have long lead times for flood warnings – sometimes many days – so effective emergency planning can help anticipate and prevent injury and death (J. Chatterton, consultant, pers. comm.). The AV score, in its current form, cannot take full account of this. The limitations of the AV could well be a function of the age of the model calibration events; the Lynmouth flood event occurred in 1952, when today's institutional arrangements, in terms of forecasting and communications technology, as well as emergency infrastructure, simply did not exist. Flood warnings, for instance, consisted of little more than personal observation. The Norwich flood event was even earlier, in 1912. The lack of modern-day institutional arrangements must be implicit in the fatalities reported for these events. In fact, the only calibration event that can be thought of as recent is the Gowdall flood of 2000, where there were no fatalities.

7.5 Summary of limitations of the current Risk to People model for application in a European context

The *Risk to People* model was developed for the UK under a number of constraints. Moreover, the Hazard Rating component of the formula clearly was not designed for the major rivers and mountainous catchments of Continental Europe. The extreme values for HR generated by the European data contribute to the dramatic over-predictions that have been described.

Insufficient account is also taken of institutional arrangements such as evacuation and rescue operations in the Area Vulnerability component of the model. In addition, the model is hugely sensitive to People Vulnerability which is arguably of less importance in the wider European context than it is in the UK.

The model was found to contain two structural weaknesses: a Hazard Rating of greater than 50 yields the result that more fatalities are predicted than injuries; when HR and PV values are high the model becomes unstable and tends to predict more injured people than are in the hazard zone.

Although redesigning the model would ideally require good quality data from many more flood events, some simple alterations have been made to the existing model in an attempt to improve its predictive capability. These modifications to the model are discussed in the following Section.

8. Adaptations and revisions to the UK *Risk to People* model

This Section explores potential refinements and revisions to the current model and attempts to develop a new product which more accurately models Continental European fatalities. The aim was to reduce the number of fatalities predicted by the model to more realistic levels whilst retaining the relationship between predicted fatalities and flood severity, as represented by the Hazard Rating.

From the statistical analyses of the data there were clearly two events that were influencing the modelling results: the Troubky (Czech Republic) datasets and also Duszniki Zone C (Poland). The basic correlation coefficient between the predicted deaths and the actual deaths in these cases illustrates this: where present the correlation coefficient is only 0.357. Once these datasets were removed from the dataset of European events the correlation coefficient improved to 0.588. For this analysis, the Czech Republic case studies (including Troubky) were also removed because, unlike the other European case studies, these represented slow-rise floods rather than rapid-onset events. Additionally, Duszniki Zdroj zone c was removed because of its negative effect on the correlations between actual and predicted deaths.

A major problem with respect to adapting the model to better suit the conditions found in Continental Europe is that more than half of the case studies where deaths occur (10 out of 18) have an actual fatality count of one, regardless of flood severity, or indeed any other model parameters. There is no correlation of any kind between the actual fatality count and flood severity, or other model parameters, even if those ten cases (with an actual fatality count of one) are removed from the dataset. Ideally, good quality data from many more case studies, with a range of flood parameters and a corresponding range of fatality counts would be needed in order to redesign the *Risk to People* model. However, in the absence of this, the model was revised in ways that seemed logical to the researchers.

Because there is no correlation between predicted and actual fatalities in the case studies so far obtained, it did not seem appropriate to test the model amendments just by correlating the revised model outputs with the actual death count. Each time a revision was made to the model, the parametric and nonparametric correlation coefficients were calculated for predicted fatalities versus Hazard Rating and predicted fatalities versus actual fatalities. The coefficients were calculated both for the full dataset (minus the four case studies mentioned above, N=30) and for those case studies that reported fatalities (N=14). These results were compared with the equivalent results for the complete dataset (N=34) and it was confirmed that excluding the four case studies mentioned above did improve the correlation coefficients.

8.1 Refinements to the current model variables

8.1.1 Removal of model coefficients

It has been noted that in the calculation for injuries, a multiplying factor of two is applied to the Nz component in the calculation for injuries; the same factor is applied to injuries in order to obtain the estimate of fatalities. The origin of this factor is not clear, so in the first place, this parameter was deleted from the injuries equation, and then from both equations to see what effect this had on model outcomes. The results are shown in Table 8.1 while the correlations are shown in Table 8.2. As was to be expected, removing the factor of two from the formulas had a linear effect on model outputs, reducing the predicted fatalities by fifty percent with respect to the injuries formula. Removing the factor from both injuries and fatalities formulas reduced predicted fatalities by 75 per cent. The linearity of the effect of removing the coefficients is further reflected in the correlations, which remain unchanged. Although there is still no meaningful correlation between actual and predicted deaths, the changes to the formula do bring down the predicted fatalities whilst maintaining the relationship between the predictions and the HR.

Table 8.1: Model results when multiplying factors are removed compared to original predictions

Flood event/location	Hazard Rating	Original model predictions	Multiplier of 2 removed from injuries formula	Multiplier of 2 removed from both formulas	Actual deaths
Fella a	9.8	9.1	4.6	2.3	1
Fella b	11.5	13.2	6.6	3.3	1
Cassano Murge	17.5	1,492.1	746.0	373.0	7
Fortezza	39.0	5.1	2.6	1.3	5
Calonge	3.0	8.2	4.1	2.0	1
Cambrils	6.0	1.7	0.9	0.4	3
La Farinera	6.0	4.0	2.0	1.0	1
Magarola	47.5	151.6	75.8	37.9	4
Klodzko gmina zone c	21.9	91.9	45.9	23.0	1
Klodzko town zone a	23.0	26.7	13.3	6.7	1
Klodzko town zone c	69.3	1,841.5	920.7	460.4	5
Miedzylesie zone b	12.0	32.2	16.1	8.1	1
Stronie Slaskie zone a	43.0	710.0	355.0	177.5	1
Dresden	9.1	7.9	4.0	2.0	1
Erlln	7.7	0.7	0.4	0.2	0
Grimma	23.0	131.0	65.5	32.8	0
Eilenburg	10.0	5.3	2.7	1.3	0
Bystrzyca Klodzka	53.5	206.1	103.0	51.5	0
Stronie Slaskie zone b	22.0	116.2	58.1	29.0	0
Polanica Zdroj	53.5	235.6	117.8	58.9	0
Miedzylesie zone c	16.8	8.4	4.2	2.1	0
Miedzylesie zone a	27.3	78.9	39.5	19.7	0
Ladek Zdroj zone d	12.0	6.0	3.0	1.5	0
Ladek Zdroj zone b	26.3	33.2	16.6	8.3	0
Ladek Zdroj zone a	17.5	7.1	3.5	1.8	0
Duszniki zdroj zone b	43.0	878.6	439.3	219.7	0
Klodzko gmina zone a	12.0	3.3	1.7	0.8	0
Bystrzyca Klodzka zone b	12.0	21.8	10.9	5.4	0
Klodzko town zone d	23.0	7.1	3.6	1.8	0
Klodzko gmina zone b	21.9	8.1	4.0	2.0	0

Table 8.2: Correlation coefficients for Table 8.1

Correlation coefficient Spearman's rho	Original model predictions	Multiplier of 2 removed from injuries formula	Multiplier of 2 removed from both formulas	Actual deaths
Predicted fatalities vs Hazard Rating Whole dataset N=30	**0.71	**0.71	**0.71	-0.07
Predicted fatalities vs Hazard Rating Fatalities only N=14	**0.73	**0.73	**0.73	0.45
Predicted fatalities vs actual Whole dataset N=30	0.13	0.13	0.13	
Predicted fatalities vs actual Fatalities only N=14	0.27	0.27	0.27	
** Correlation significant at the 0.01 level				

8.1.2 Population in the affected zone (Nz)

The sensitivity analysis (Section 7) revealed that the Nz component of the model has a strong linear influence on the outcomes. The Nz component was transformed using a variety of methods, two of which are shown below in Table 8.3 with the relevant correlation coefficients shown in Table 8.4.

Table 8.3: Model results with transformed values of Nz compared to original predictions

Flood event/location	Hazard Rating	Original model predictions	Log10 of Nz	Square root of Nz	Actual deaths
Fella a	9.8	9.1	0.1	0.5	1
Fella b	11.5	13.2	0.1	0.6	1
Cassano Murge	17.5	1,492.1	0.3	10.6	7
Fortezza	39.0	5.1	0.2	0.7	5
Calonge	3.0	8.2	0.0	0.2	1
Cambrils	6.0	1.7	0.0	0.0	3
La Farinera	6.0	4.0	0.0	0.3	1
Magarola	47.5	151.6	1.3	8.8	4
Klodzko gmina zone c	21.9	91.9	0.3	2.8	1
Klodzko town zone a	23.0	26.7	0.3	1.9	1
Klodzko town zone c	69.3	1,841.5	2.5	36.8	5
Miedzylesie zone b	12.0	32.2	0.1	1.1	1
Stronie Slaskie zone a	43.0	710.0	1.2	15.9	1
Dresden	9.1	7.9	0.1	0.5	1
Erlln	7.7	0.7	0.0	0.1	0
Grimma	23.0	131.0	0.3	3.8	0
Eilenburg	10.0	5.3	0.0	0.3	0
Bystrzyca Klodzka	53.5	206.1	1.2	9.7	0
Stronie Slaskie zone b	22.0	116.2	0.8	5.8	0
Polanica Zdroj	53.5	235.6	1.5	11.5	0
Miedzylesie zone c	16.8	8.4	0.1	0.7	0
Miedzylesie zone a	27.3	78.9	0.5	4.1	0
Ladek Zdroj zone d	12.0	6.0	0.0	0.3	0
Ladek Zdroj zone b	26.3	33.2	0.3	2.1	0
Ladek Zdroj zone a	17.5	7.1	0.1	0.5	0
Duszniki zdroj zone b	43.0	878.6	5.2	41.4	0
Klodzko gmina zone a	12.0	3.3	0.1	0.3	0
Bystrzyca Klodzka zone b	12.0	21.8	0.1	0.7	0
Klodzko town zone d	23.0	7.1	0.4	1.3	0
Klodzko gmina zone b	21.9	8.1	0.2	0.8	0

Table 8.4 shows that the transformations led to an improved correlation between predicted fatalities and Hazard Rating. The correlation between predicted and actual deaths is reduced when all case studies are considered but increased when only those case studies that reported fatalities are considered.

Table 8.4: Correlation coefficients for Table 8.3

Correlation coefficient (Spearman's rho)	Original model predictions	Log10 of Nz	Square root of Nz	Actual deaths
Predicted fatalities vs Hazard Rating (whole dataset) N=30	**0.71	**0.93	**0.88	-0.07
Predicted fatalities vs Hazard Rating (fatalities only) N=14	**0.73	**0.95	**0.90	0.45
Predicted fatalities vs Actual (whole dataset) N=30	0.13	-0.03	0.02	
Predicted fatalities vs Actual (fatalities only) N=14	0.27	0.43	0.38	
** Correlation significant at the 0.01 level				

8.1.3 Hazard rating formula

According to the sensitivity analysis, the Hazard Rating has a strong influence on model results. Transformations were then applied to the hazard rating in order to decrease its impact on the model and to see if this resulted in improved predictions. Note that the hazard rating is factored in twice to the model calculation, in both the injuries and fatalities formulas. The results are shown in Table 8.5 below, with the correlations shown in Table 8.6.

The result of these transformations was that the relationship between predicted fatalities and flood severity (Hazard Rating) decreased, whilst the relationship between actual and predicted deaths is not significantly increased.

8.1.4 Area vulnerability

As noted in Section 7, the Area Vulnerability component of the formula does not appear to have sufficient influence on the model outputs. The sensitivity analysis also revealed that making changes to the individual elements of this component has only a weak effect on model outputs. So, rather than carrying out transformations on the AV variables, it was considered more appropriate to change the way that AV is utilised in the model. Various changes were therefore made to the formula in an attempt to address this issue:

AV amendment 1: The AV score was divided by 10 and then used as a multiplier instead of PV, which was omitted from the formula.

Revised equation:

$$Ninj = 2Nz*\left(\frac{HR}{100}\right)*\left(\frac{AV}{10}\right)$$

AV amendment 2: The AV score was inverted (i.e. a value of one represents high risk while a value of three denotes low risk) so that AV represents *resilience*, rather than vulnerability. The AV was then subtracted from HR.

Revised equation:

$$Ninj = 2Nz*\left(\frac{HR-AV}{100}\right)*PV$$

.

AV amendment 3: As amendment 2 but the range of scores is doubled from 3 to 6.

The results of these alterations are shown below in Table 8.7 while the correlation coefficients are shown in Table 8.8.

Table 8.5: Model results with transformed values of HR compared to original predictions

Flood event/location	Hazard Rating	Original model predictions	Log10 of HR	Square root of HR	Actual deaths
Fella a	9.8	9.1	0.1	0.9	1
Fella b	11.5	13.2	0.1	1.2	1
Cassano Murge	17.5	1,492.1	7.5	85.3	7
Fortezza	39.0	5.1	0.0	0.1	5
Calonge	3.0	8.2	0.2	2.7	1
Cambrils	6.0	1.7	0.0	0.3	3
La Farinera	6.0	4.0	0.1	0.7	1
Magarola	47.5	151.6	0.2	3.2	4
Klodzko gmina zone c	21.9	91.9	0.3	4.2	1
Klodzko town zone a	23.0	26.7	0.1	1.2	1
Klodzko town zone c	69.3	1,841.5	1.3	26.6	5
Miedzylesie zone b	12.0	32.2	0.3	2.7	1
Stronie Slaskie zone a	43.0	710.0	1.0	16.5	1
Dresden	9.1	7.9	0.1	0.9	1
Erlln	7.7	0.7	0.0	0.1	0
Grimma	23.0	131.0	0.5	5.7	0
Eilenburg	10.0	5.3	0.1	0.5	0
Bystrzyca Klodzka	53.5	206.1	0.2	3.9	0
Stronie Slaskie zone b	22.0	116.2	0.4	5.3	0
Polanica Zdroj	53.5	235.6	0.2	4.4	0
Miedzylesie zone c	16.8	8.4	0.0	0.5	0
Miedzylesie zone a	27.3	78.9	0.2	2.9	0
Ladek Zdroj zone d	12.0	6.0	0.0	0.5	0
Ladek Zdroj zone b	26.3	33.2	0.1	1.3	0
Ladek Zdroj zone a	17.5	7.1	0.0	0.4	0
Duszniki zdroj zone b	43.0	878.6	1.3	20.4	0
Klodzko gmina zone a	12.0	3.3	0.0	0.3	0
Bystrzyca Klodzka zone b	12.0	21.8	0.2	1.8	0
Klodzko town zone d	23.0	7.1	0.0	0.3	0
Klodzko gmina zone b	21.9	8.1	0.0	0.4	0

Table 8.6: Correlation coefficients for Table 8.5

Correlation coefficient (Spearman's rho)	Original model predictions	Log10 of HR	Square root of HR	Actual deaths
Predicted fatalities vs Hazard Rating (whole dataset) N=30	**0.71	*0.44	**0.52	-0.07
Predicted fatalities vs Hazard Rating (fatalities only) N=14	**0.73	0.41	0.51	0.45
Predicted fatalities vs Actual (whole dataset) N=30	0.13	0.20	0.18	
Predicted fatalities vs Actual (whole dataset) N=14	0.27	0.14	0.20	
** Correlation significant at the 0.01 level				

Table 8.7: Model results with AV amendments compared to original predictions

Flood event/location	Hazard Rating	Original model predictions	AV1	AV2	AV3	Actual deaths
Fella a	9.8	9.1	9.1	1.4	1.3	1
Fella b	11.5	13.2	13.2	2.5	2.3	1
Cassano Murge	17.5	1,492.1	1,715.0	207.1	201.0	7
Fortezza	39.0	5.1	25.6	0.7	0.7	5
Calonge	3.0	8.2	3.3	1.0	0.8	1
Cambrils	6.0	1.7	17.3	0.3	0.2	3
La Farinera	6.0	4.0	2.6	0.4	0.4	1
Magarola	47.5	151.6	189.5	21.4	21.2	4
Klodzko gmina zone c	21.9	91.9	120.9	14.9	14.5	1
Klodzko town zone a	23.0	26.7	29.6	3.7	3.6	1
Klodzko town zone c	69.3	1,841.5	2,877.3	304.3	301.6	5
Miedzylesie zone b	12.0	32.2	35.3	4.4	4.2	1
Stronie Slaskie zone a	43.0	710.0	1,183.4	87.9	87.1	1
Dresden	9.1	7.9	7.9	1.0	0.9	1
Erlln	7.7	0.7	1.4	0.1	0.1	0
Grimma	23.0	131.0	152.4	21.3	20.7	0
Eilenburg	10.0	5.3	6.6	0.8	0.8	0
Bystrzyca Klodzka	53.5	206.1	412.2	25.6	25.4	0
Stronie Slaskie zone b	22.0	116.2	46.5	18.8	18.3	0
Polanica Zdroj	53.5	235.6	336.6	33.3	33.0	0
Miedzylesie zone c	16.8	8.4	9.3	1.3	1.3	0
Miedzylesie zone a	27.3	78.9	87.7	9.7	9.6	0
Ladek Zdroj zone d	12.0	6.0	8.6	1.1	1.1	0
Ladek Zdroj zone b	26.3	33.2	41.5	5.4	5.3	0
Ladek Zdroj zone a	17.5	7.1	8.8	1.7	1.6	0
Duszniki zdroj zone b	43.0	878.6	266.3	108.8	107.8	0
Klodzko gmina zone a	12.0	3.3	4.1	0.5	0.5	0
Bystrzyca Klodzka zone b	12.0	21.8	36.3	3.4	3.3	0
Klodzko town zone d	23.0	7.1	4.4	1.0	1.0	0
Klodzko gmina zone b	21.9	8.1	11.5	1.3	1.3	0

Table 8.8: Correlation coefficients for Table 8.7

Correlation coefficient (Spearman's rho)	Original model predictions	AV1	AV2	AV3	Actual deaths
Predicted fatalities vs Hazard Rating (whole dataset) N=30	**0.71	**0.78	**0.75	**0.75	-0.07
Predicted fatalities vs Hazard Rating (fatalities only) N=14	**0.73	**0.84	**0.73	**0.74	0.45
Predicted fatalities vs Actual (whole dataset) N=30	0.13	0.21	0.08	0.08	
Predicted fatalities vs Actual (fatalities only) N=14	0.27	*0.55	0.27	0.27	
** Correlation significant at the 0.01 level * Correlation significant at the 0.05 level					

The fatality figures are substantially reduced whilst the strong relationship with the Hazard Rating is retained. In addition, there is now a significant correlation – albeit at the 0.05 level – between actual fatalities and the AV1 method. The rationale for the AV1 method was to eliminate PV from the equation, since PV may not be important in the European context. This view is supported (or at least not refuted) by the fact that the AV1 method yields a significant correlation between actual and predicted fatalities.

AV2 rationale: as mentioned in Section 7 it was suggested that the AV score could be separated into two elements; a score for the vulnerability of the area and a score for the effectiveness of risk management measures. The latter would be a negative number that would therefore reduce the overall AV score. However, as shown in the sensitivity analysis, AV does not have enough influence on the model outcomes, so reducing it does not seem sensible. Instead, AV was inverted to a measure of resilience and subtracted from the HR.

AV3 rationale: it has been suggested that the range of AV variables could be increased to include such things as flood-awareness and building collapse. Doubling the AV score simulates the effects of including an increased range of variables. The AV is still inverted to a measure of resilience, rather than vulnerability, because the model is overestimating deaths; if the AV score was to be left as a measure of vulnerability, doubling the score would increase the predicted fatalities. However, doubling the range did not have a significantly different outcome to the AV inversion method (AV2) described above, indicating that including more variables in the AV score will not, on its own, make a substantial difference.

8.1.5 People vulnerability

The sensitivity analysis demonstrated that the model is very sensitive to People Vulnerability because of this component's role as a multiplier in the injuries equation. In order to reduce the number of predicted injuries and fatalities, the effect of PV should be reduced. However, because PV is a percentage value, routine log and square root transformations have the effect of increasing the influence of PV. In the first place, the PV values were converted to numbers, so that for instance 10% becomes 10, the effect of using the reciprocal (1/PV) was then tested. Retaining the PV value as a percentage, various power functions (>1) were applied to the PV. The results are shown below in Table 8.9 with the correlation coefficients given in Table 8.10.

The most promising result obtained was for the reciprocal of PV (where PV is an absolute value, not a percentage) in this case the correlation between predicted fatalities and HR is improved, as are the correlations between predicted and actual fatalities. When only the case studies that involved fatalities are considered, there is a significant correlation at the 0.05 level between predicted and actual fatalities.

8.2 Data analyses

The remaining analyses discussed in Section 8 look in more detail at the European data to try to understand which factors are most important to the assessment of risk to life within the wider European context. This had been achieved by performing a number of statistical analyses to explore the datasets in more detail and understand the relationships between the different variables and the numbers who died during flooding events. These data variables can be seen in Table 8.11.

It was first necessary to include those additional factors which were not examined within the *Risk to People* methodology but have been highlighted (in Section 3.7) as being potentially important in assessing the risk from flooding in Continental Europe. There are a number of ways in which each of these variables might therefore have been included. In a number of cases these factors have been represented in more than one way to try to capture whether or not they are significant.

Table 8.9: Model results with PV amendments compared to original predictions

Flood event/location	Hazard Rating	Original model predictions	1/PV	PV^1.5	PV^1.75	PV^2	Actual deaths
Fella a	9.8	9.1	9.1	2.9	1.6	0.9	1
Fella b	11.5	13.2	13.2	4.2	2.4	1.3	1
Cassano Murge	17.5	1,492.1	1,971.3	440.1	239.0	129.8	7
Fortezza	39.0	5.1	127.8	0.7	0.3	0.1	5
Calonge	3.0	8.2	1.3	4.1	2.9	2.0	1
Cambrils	6.0	1.7	172.8	0.2	0.1	0.0	3
La Farinera	6.0	4.0	1.7	1.6	1.0	0.6	1
Magarola	47.5	151.6	236.9	42.9	22.8	12.1	4
Klodzko gmina zone c	21.9	91.9	159.0	25.3	13.3	7.0	1
Klodzko town zone a	23.0	26.7	32.9	8.0	4.4	2.4	1
Klodzko town zone c	69.3	1,841.5	4,495.8	465.9	234.3	117.9	5
Miedzylesie zone b	12.0	32.2	38.7	9.7	5.4	2.9	1
Stronie Slaskie zone a	43.0	710.0	1,972.3	173.9	86.1	42.6	1
Dresden	9.1	7.9	7.9	2.5	1.4	0.8	1
Erlln	7.7	0.7	2.8	0.2	0.1	0.0	0
Grimma	23.0	131.0	177.2	38.4	20.8	11.3	0
Eilenburg	10.0	5.3	8.1	1.5	0.8	0.4	0
Bystrzyca Klodzka	53.5	206.1	824.3	46.1	21.8	10.3	0
Stronie Slaskie zone b	22.0	116.2	18.6	58.1	41.1	29.0	0
Polanica Zdroj	53.5	235.6	480.9	62.3	32.1	16.5	0
Miedzylesie zone c	16.8	8.4	10.3	2.5	1.4	0.8	0
Miedzylesie zone a	27.3	78.9	97.4	23.7	13.0	7.1	0
Ladek Zdroj zone d	12.0	6.0	12.3	1.6	0.8	0.4	0
Ladek Zdroj zone b	26.3	33.2	51.9	9.4	5.0	2.7	0
Ladek Zdroj zone a	17.5	7.1	11.0	2.0	1.1	0.6	0
Duszniki zdroj zone b	43.0	878.6	80.7	504.7	382.6	290.0	0
Klodzko gmina zone a	12.0	3.3	5.2	0.9	0.5	0.3	0
Bystrzyca Klodzka zone b	12.0	21.8	60.5	5.3	2.6	1.3	0
Klodzko town zone d	23.0	7.1	2.8	2.8	1.8	1.1	0
Klodzko gmina zone b	21.9	8.1	16.4	2.1	1.1	0.6	0

Table 8.10: Correlation coefficients for Table 8.9

Correlation coefficient (Spearman's rho)	Original model predictions	1/PV	PV^1.5	PV^1.75	PV^2	Actual deaths
Predicted fatalities vs Hazard Rating N=30	**0.71	**0.72	**0.68	**0.66	**0.64	-0.07
Predicted fatalities vs Hazard Rating N=14	**0.73	**0.77	**0.68	*0.63	*0.63	0.45
Predicted fatalities vs actual N=30	0.13	0.30	0.11	0.12	0.14	
Predicted fatalities vs actual N=14	0.27	*0.65	0.23	0.24	0.24	
** Correlation significant at the 0.01 level * Correlation significant at the 0.05 level						

Table 8.11: The different variables that are included within the statistical analyses

Variable	Description
Risk to People	*Factors included within the original Risk to People methodology*
Population at risk (Nz)	The population who are in the risk zone and who are at risk from the flood
Depth	The depth of the flood (in metres)
Velocity	The Velocity of the flood (in metres per second)
Debris factor (DF)	A factor related to the amount of debris found in the flood waters (A factor of 0, 0.5 or 1 is assigned)
Speed of onset	Speed of onset is represented as an ordinal scale: 1. Slow onset 2. Medium onset 3. Rapid onset
Nature of area	An ordinal scale with variables representing the characteristics of the area: 1. Multi-storey apartments 2. Typical residential area (2-storey homes); commercial and industrial properties 3. Bungalows, mobile homes, busy roads, parks, single storey schools, campsites, etc.
Flood warning	Flood warning is represented as an ordinal scale: 1. Good - Where the majority of people at risk received warning with adequate lead time 2. Fair - Warning received by some of the population with adequate lead time 3. None - No warnings received
Percentage of the long-term ill	An estimation of the percentage of the ‘at risk’ population that are long-term unwell
Percentage of over-75 years	An estimation of the percentage of the ‘at risk’ population that are over the age of 75 years
Alternative Risk to People variable representations	*These are where actual measures have been used rather than putting these factors on an ordinal scale*
Lead time of flood warning	This factor is presented in minutes and constitutes the length of time before the flooding a warning was given.
Actual time to flood onset	This is the time from when the first signs of change were noticed in water levels or from signs of precipitation to when the floods threaten people and their property (in minutes).
New variables	
Awareness of flood risk	This has been developed on an ordinal scale of; 1. High awareness 2. Medium awareness 3. Low awareness
Building collapse (1)	This is a presence/absence factor which indicates whether buildings collapsed or not.
Building collapse (2)	This variable is the actual numbers of buildings that collapsed during the flooding
Building collapse (3)	A ratio of buildings collapsed to population at risk from flooding
Evacuation (1)	A presence/absence variable (represented as 1, 0) representing whether people were evacuated from the flooded zone
Evacuation (2)	The percentage of people at risk that were evacuated AFTER the flood event
Evacuation (3)	The percentage of people at risk that were evacuated BEFORE or DURING the flood event
Evacuation (4)	The percentage of people at risk that were evacuated EITHER before or after the flood event
Flood Duration	The length of time a zone has experienced flooding (in hours)
Population with language constraints (1)	This is a presence/absence value which is evaluating whether language constraints are problematic
Population with language constraints (2)	This is the percentage of the population at risk that have particular language constraints.
Time of the flood	This is a factor (1,0) which indicated whether the flooding occurred during the day or the night.

8.2.1 Evacuation

This was obviously included because of its increased significance within the European context and the impact that it has upon the population at risk (Nz). Four different classes of evacuation were added to the data analyses. This was necessary because of the fact that there were people evacuated before and during flooding and also in some cases after the event had occurred. In addition to the two classes described above two general components were created: one which merely showed whether evacuation was present or absent and a second variable where the percentages of the population at risk that were evacuated were presented. The first component was important as there were some data sets where it was reported that evacuation had taken place, but no further details about when it occurred or how many people were affected.

8.2.2 Building collapse

A further factor that appears to be more significant in European flooding than in the UK is the presence of buildings that collapse due to the larger depths and higher velocities that are often experienced. This may also be a function of building types, materials or construction standards. Again in this case it was important to represent building collapse in a range of ways. Firstly, similar to the evacuation component a presence or absence of building collapse was added to signal whether this was an important variable. Following this, where there was data, a second variable was added which was the number of buildings that collapsed. Finally, it was felt to be important to try to provide some kind of scale in relation to the building collapse, for instance if 10 buildings collapsed in a small village this might be more significant than if the same number of properties were destroyed in a large city. Ideally, this would have been represented by ascertaining the percentage of the properties that collapsed. However, the total number of properties within a risk zone was not known in some cases, and to ensure consistency among datasets a ratio between the population at risk and the numbers of properties that collapsed was used. Although therefore not the most accurate measure, it was hoped that this would provide some kind of judgement about the scale of the significance of the building collapse.

8.2.3 Awareness of flood risk

As this variable is very difficult to quantify, data were input on an ordinal scale similar to the categories of *Speed of onset, Flood warning* and *Nature of area* in the original *Risk to People* methodology. Therefore, when the data were collected, respondents were asked to estimate whether awareness of flood risk within the area was high, medium or low. Although only an estimate, and in most cases the categorisation of a low awareness of risk was selected, it was considered important to test to see whether there was any significance in this variable. That is, whether it had a positive or negative impact upon flood risk.

8.2.4 Visitors and language constraints

The original *Risk to People* methodology and other models (including Brown and Graham, 1988; Zhai *et al.*, 2006; Jonkman, 2007) indicate that the population at risk is a key factor in establishing the risk from flooding and how many fatalities will occur. Taking a true measure of that population at risk is very difficult to achieve. In some respects when collecting the data for this study, those estimating the population at risk were asked to take this variable into consideration and to identify as accurately as possible how many people were in the risk zones, whether they lived there or were visiting the area. In addition, it was felt important to see whether there were any other risks associated with the presence of visitors in the area. The obvious factors would relate to whether there were any significant changes in flood risk awareness because of the numbers of visitors to an area. Coupled with this is whether there are any language constraints. This might mean that people would not be able to follow instructions either speedily or adequately following a flood warning. Therefore, this factor was added to the analysis with two variables. A presence and absence value (1 and 0) and as a percentage of the population at risk where this was available (unfortunately there was only one flood zone where a percentage value was given for this variable).

8.2.5 Duration of the flood

Within the statistical analysis the duration of the flood was entered simply as the length of the time of the flooding in hours. There are difficulties in defining how long a flood lasts, particularly if it is a large slow rising flood and water is around for a long period of time. Also there is the problem of the discontinuity of timing across the risk zone. However, in this instance the duration has been taken as how long the water was outside of the main channel and overbank conditions were experienced. Where this varies across the risk zone an average has been taken.

8.2.6 Time of day of flooding

As already mentioned in Sections 2.3.1 and 5.4.2, the time of day of the flooding, and in particular the onset of the flooding was a factor considered to be worth investigating within the statistical analysis. The time of day when a flood begins might not only impact upon the numbers of people within the risk zone (and therefore Nz), but it might also impact upon the ability of people to get a visual warning from flooding or respond when flooding has begun. Pragmatically, it is very difficult to include the presence of this variable within a numerical analysis. Therefore it has only been recorded whether the flood began in the daytime or at night. In reality, the circumstances surrounding the time of day are likely to make it very difficult if not impossible to model effectively as in some circumstances it will have a positive effect and in others a negative impact upon the numbers of fatalities caused by flooding.

In addition to the introduction of different variables it was also important to investigate in more detail those aspects already within the model that might be represented in a different way. Therefore two new variables were added: actual speed of onset and warning lead time.

8.2.7 Actual speed of onset

Speed of onset was to enhance the ordinal variable within the original *Risk to People* model which presented this information on a scale of 1 to 3. Where possible for the European case studies this information has been enhanced and the actual speed of onset (defined as the time between the water rising above normal to it threatening people and their property) has been adopted with the information being estimated in minutes.

8.2.8 Lead time of flood warning

To try to get a better understanding about whether flood warnings are impacting on the numbers of deaths from flooding it was necessary to increase the amount of information provided about flood warnings. As discussed in Section 3.7, the original *Risk to People* methodology had to be altered from the outset to contend with a reduction in the amount of information available in Europe compared with the information about flood warnings collected by the UK’s Environment Agency. In addition to this scale of *Good*, *Fair* and *No warning*, it has been possible to estimate in most cases the lead time given before the flood to try to estimate whether the people who have received a flood warning have the chance to react. Of course, what this factor does not take into consideration is whether people understand and believe the warning or take effective action.

When testing the variables additional to the *Risk to People* methodology it has been necessary to exclude certain datasets (primarily Norwich due to the age of the event, 1912) as all of this additional data was not available.

8.3 Cluster analysis

It became apparent early on that some of the datasets appeared to be affecting the results of the statistical tests more than others. Therefore, prior to investigating the specific variables it was important to investigate the actual case studies themselves, their influence and their integrity. A cluster analysis was therefore performed on the observations of the data. This was intended to look at all of the data points and to highlight those cases which appear to be very different from the others. It was therefore possible to say whether any of the datasets should either be looked at in more detail or excluded from further analyses. In order to identify whether there were any significant groupings, dendrograms have been drawn of the results (as show in Figures 8.1 and 8.2).

A number of cluster analyses were performed to suggest whether there was any grouping in the data. Firstly, the analysis was performed on all of the data with both the UK and European cases (n=45, which have in total 92 deaths). However, although this analysis did indicate that there were some datasets that were different from others, because of the missing data within the two Norwich datasets it was decided to exclude these and rerun the analysis on the remaining 43 datasets. The results of the subsequent analysis can be visualised in Figure 8.1. This dendrogram shows that there are some observations that appear to be quite different from others.

In this instance the cluster analysis was able to be performed on 14 of the 22 variables. This included 7 of the original *Risk to People* categories (Nz, death, velocity, DF speed of onset, nature of area, flood warning), the actual numbers of people who died, and the additional variables of building collapse (1 to 3), population with language constraint 1 and the time of the flood.

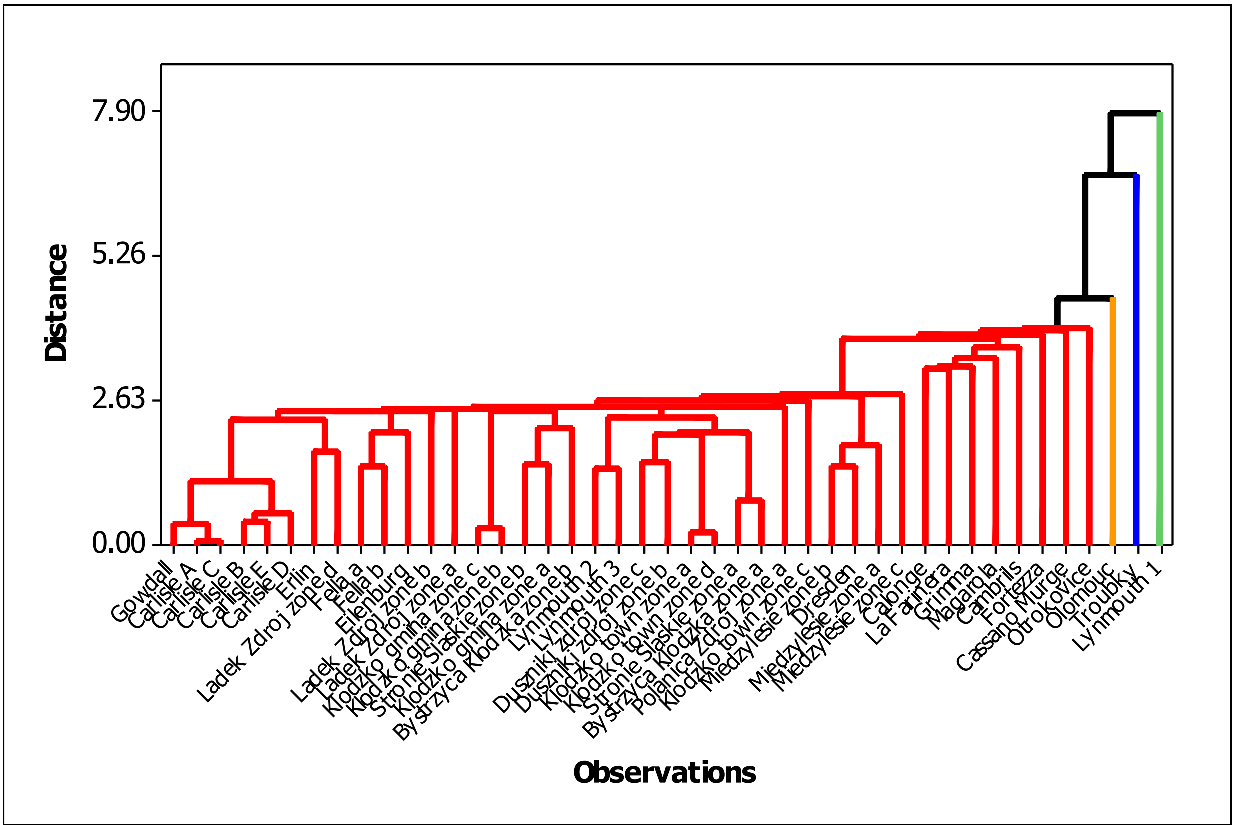


Figure 8.1: Dendrogram of all of the data (minus Norwich) – Single Linkage and Euclidean distance

The dendrogram illustrates that there are really three events that stand out as being different from the rest; Olomouc, Troubky (both from the Czech Republic) and Lynmouth zone 1. The cases of Olomouc and Troubky will be discussed in more detail in the analysis below, however it is pertinent to discuss the relevance of Lynmouth zone 1 being highlighted. One thing to note from the outset is the fact that as Norwich has been taken out of the analysis for data availability reasons, occurring in 1952 this is clearly the oldest dataset that is still present. All of the other datasets are from after 1997. This will clearly impact on a number of the factors being analysed such as search and rescue and flood warnings and therefore the validity of using this data might be questioned. However, it is only Lynmouth zone 1 that is being highlighted as being different; the other two zones are clearly similar to the more modern event data.

Lynmouth zone 1 was the worst affected of the zones that were flooded and was where 28 people were killed. It was the zone closest to the river and was affected by high depths and velocities (see Section 5.2.1) and was where 39 buildings collapsed. This event is considered to be different to the type of flooding that is usually experienced in the UK which usually tends to be slower rise longer-term events. When flash flooding does occur, the velocities and depths experienced are not generally so severe. Indeed, although flooding often causes structural problems, this is one of the few UK flooding events where building collapse has been documented. Due to the sheer number of deaths (28% of the population at risk perished) and the circumstances surrounding the fatalities, the Lynmouth event also appears to be very different to the majority of events in Continental Europe. Twenty-two of those who died were killed when their properties collapsed. This is similar to the Troubky case where all of the nine deaths were caused by building collapse.

It was also felt necessary to repeat this analysis only for the Continental European flood events. This was important as for these observations data issues were fewer and permitted the majority of the data variables to be included.

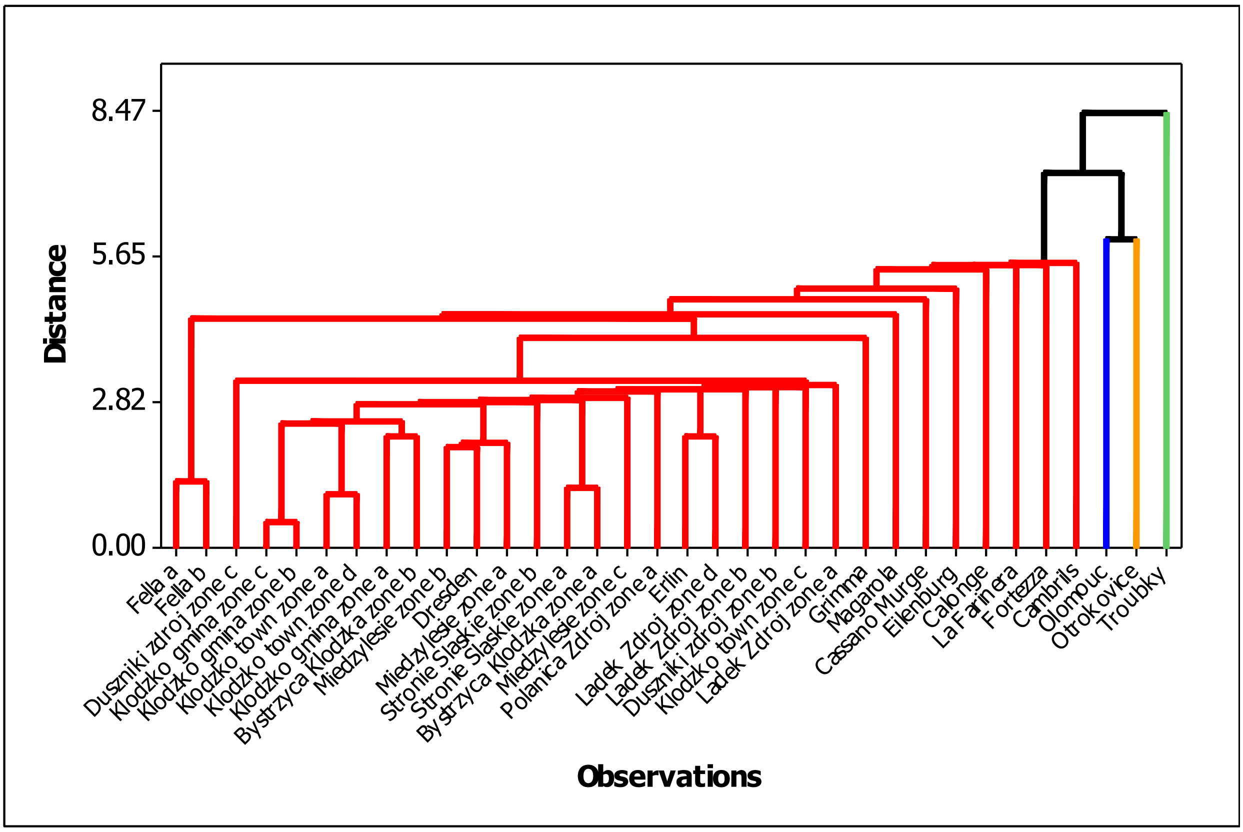


Figure 8.2: Dendrogram of all of the European data – Single Linkage and Euclidean distance

In this analysis 20 variables were examined. These included all of the 9 variables in the original *Risk to People* categories (Nz, death, velocity, DF speed of onset, nature of area, flood warning, % of long term ill and % of over 75 years), the actual deaths that occurred because of flooding and 10 additional variables (awareness of flood risk, building collapse categories 1 to 3, presence of evacuation, population with language constraints, time of the flood, actual speed of flood onset, lead time of flood warning).

The dendrogram shows a similar pattern to the analysis performed on all of the data above. The events of Troubky and Olomouc appear again to be presented as different from the other data. In this analysis these two datasets are joined by that of Otrokovice. This result is interesting as these three case studies are all of the data points from the Czech Republic and although according to the scale adopted only Otrokovice and Olomouc are truly designated as slow onset floods, the circumstances surrounding the flooding in Troubky were also comparable with a slow rise in flood waters. The flood that affected the village of Troubky had begun to rise in the area over the previous day, however it was unexpected that the flooding would reach the village in the manner that it did. The surrounding land cover (corn field) contributed to the change in flood characteristics and it was suggested that in the surrounding area 3 square kilometres of corn wheat fields were saturated. After the saturation and laying down of the wheat, the water suddenly moved directly into the village under what the locals called the “brush effect”.

The result was that the water level rose by 1.5 to 2 metres in around 10 minutes and in some places reached a depth of 2.5m. Therefore, although some of the specifics of this dataset (such as speed of onset and actual time to onset of flooding) do not really indicate it, the overall picture of flooding in this region was a slow onset, long duration flood. In addition, as described in Section 5.4.3, the circumstances surrounding the nine deaths in this case study were all attributed to structural collapse which was different to the majority of the other datasets. Due to the difficulties in sourcing the data on flooding, there are only three observations which can truly be considered to be slow onset flooding and therefore it should be questioned whether these three events should be included within the sample or whether they are having too large an effect on the results.

The cluster analysis has highlighted that there are four datasets that are appearing to be different from the rest of the data and potential reasons for this have been described above. It is necessary however to consider the potential influence of these four datasets on the results of the statistical analyses and therefore how they should be treated. Therefore, different groups of datasets were used (where appropriate) within the analyses. For instance, an examination of all of the data was performed and then further examinations without the inclusion of those cases that have been identified as being potentially atypical. It should be remembered however that if results were generated from a group of events that, for instance, do not include the Czech flooding events, the results of these analyses will not have been derived or tested on the type of events that these cases represent; i.e. slow-onset long-duration flooding.

In addition to all the data being examined, it also seemed appropriate to look at those cases where deaths were recorded in isolation. This approach has been adopted due to the fact that although there may be measurable variables that are influencing whether or not fatalities are expected such as velocity or people vulnerability (and indeed in all of the cases examined deaths would indeed be expected) other factors (as described in Section 5.4) such as behaviour or chance which are very difficult to predict and include within a model may also be influential.

8.4 Principal components analysis

Principal component analysis (PCA) has been undertaken on the different datasets to highlight whether any of the variables form coherent subsets. The analysis highlights whether there are any significant groupings of variables (for instance variables related to flood characteristics, the area flooded etc) and reduces the large number of variables down to a few key components. Similar to the correlation matrices above, it was necessary to undertake the analysis on different datasets. Here it has been undertaken on all of the data and subsequently all of the data minus the Czech datasets. These results can be seen in Appendix E.

The results of the PCA were quite disappointing on all of the data as there was no grouping of datapoints that was considered to be statistically significant. In order to provide a visual representation of the data, the first two factors of the PCA have been graphed to see whether there is any significant clustering of any components that are worth investigating further. However, the results in most cases indicated no clear associations between the principal components.

Principal component analysis has also been carried out on two other datasets; those Continental European case studies with deaths and then again on those without deaths. Although the results do show slightly different results, none of the results show any strong correlations with any other key principal component.

8.5 Correlations between the variables

The data were initially subjected to some basic statistical tests to explore whether there were any statistically significant relationships within the data. A Pearson's correlation matrix was created to highlight any relationships between particular variables. This test does not highlight causation, but will give an indication of where there are relationships between variables that require further investigation and explanation. The coefficients will also highlight in particular any significant relationships between the actual numbers of people killed and those factors that might be used to estimate risk to life. Statistical significance in this test has been taken to the 90% probability level, although many of relationships are still valid to the more usually adopted 95% level.

Correlation matrices were created for a number of different sets of data. Tables of the significant output can be seen in Appendix F. These tables illustrate the relationships between the two different variables being highlighted, the Pearson's correlation coefficient and the level of statistical significance of the correlation (p-value). In addition, an explanation is provided about whether the relationship is relevant or if there is any covariance in the relationship. The key relationships are described below. It is important to note that although the correlations are statistically significant the strength of the correlations is affected by the number of observations. Therefore in addition to the presentation of the correlated variables and the significance factor, the number of observations (n) in the sample is recorded along with the total number of deaths.

Correlation matrices have been derived from the continuous variables as listed in Table 8.12 below. As all the correlations were calculated against each of the others there are obviously some variables that are covariant, such as 'evacuation before' and 'general evacuation' components. There are however, many other components that also appear to show some covariance.

Table 8.12: Variables for which Pearson's correlation coefficient has been calculated

NZ – population at risk
Depth
Velocity
Percentage of the population that are long-term ill
Percentage of the population that are over 75 years of age
Building collapse 2 (actual numbers of buildings that collapsed)
Building collapse 3 (ratio between numbers of buildings that collapsed and population at risk)
Flood duration
Percentage of the population at risk with language constraints
Evacuation (after – percentage of NZ that were evacuated either before or after the event)
Evacuation (before – percentage of NZ that were evacuated either before or after the event)
Evacuation (general – percentage of NZ that were evacuated either before or after the event)
Actual speed on onset
Lead time of the flood warning

It is important to note that differences exist between the most significant variables in those samples that included fatalities and those that did not. This is not surprising as the ideal finding would be one or more important relationships that exist to explain why deaths occurred in some scenarios and why they did not exist in others and the flood characteristics and the numbers at risk were comparable to those where deaths occurred. Section 5 investigated potential reasons why some flood event zones have deaths and others do not. Variables that might have explained the low numbers of deaths are the numbers of people being evacuated or a long lead time of flood warning. However the correlations did not show any significant relationships between the numbers of deaths and these variables. This does not necessarily mean that these variables are not important or are not having an influence but that there may be a number of variables that are influencing whether fatalities occur. There are also some variables that are not able to be represented within a model of this kind, such as people's behaviour or the role of chance.

Therefore, those events that did have fatalities have been examined in more detail separately from the full sample of data to try to identify those key variables that are leading to deaths.

8.5.1 Building collapse

When all datasets are included in the sample (n=45 and deaths=92) the only statistically significant variable that appears to be related to the numbers of people that have been killed is the presence of building collapse. Both the variables building collapse 2 (the actual numbers of buildings that collapsed during the flood) and building collapse 3 (a ratio between the population and the numbers of buildings that collapsed) are statistically significant. The relationships are both positive; that is the higher the degree of building collapse the higher the numbers of people that have been killed, however the correlations vary. Building collapse 2 has a correlation coefficient of 0.278 (p-value = 0.071) and building collapse 3 of 0.897 (p-value of 0.000).

This is an interesting relationship. However concern is expressed about whether a small number of events that have high numbers of deaths are having an effect on the relationship. The first of these is Lynmouth zone 1. In this case, as stated before in Section 5.2.1, building collapse was the main cause of death with 22 out of the 28 people being killed in this manner. In addition, the population in this zone was only 100 people and so the high correlation between death and building collapse 3 might be inflated by this figure. Following the removal of Lynmouth Zone 1 from the sample, the effect of the different categories of building collapse does appear to have been tempered. The correlation between the number of fatalities and building collapse 3 is reduced to 0.487 whereas the correlation between death and building collapse 2 is strengthened to 0.469 and becomes more statistically significant.

There is still concern that the significance of the factor of building collapse is being skewed by another of the event observations: the case of Troubky, Czech Republic, where all of the 9 reported deaths were from the collapse of buildings. Following the removal of this event from the sample the relationships between fatalities and either of the building collapse variables is no longer statistically significant. The conclusion, unsurprisingly, is that where the flood waters are severe enough to cause buildings to collapse, this appears to be a major component in leading to fatalities. However, 17 of the flood events included within the analysis had buildings or other structures that collapsed, although only 5 (deaths=18) of the events had people who were killed as a direct result of structural collapse. It is therefore pertinent to examine other factors that have a significant effect on the number of fatalities from a flood event.

8.5.2 People vulnerability components

One of the three main components of the *Risk to People* methodology was to try to include aspects related to people vulnerability and identify those who are most vulnerable to the effects of flooding. The work undertaken by HR Wallingford (2005a, p16-17) identified a number of different groups that might be described as being more vulnerable to flooding, including the financially deprived, single parents and children, the homeless, and those undertaking leisure-related activity. However, the original *Risk to People* project identified the percentage of the population over the age of 75 years and the percentage of the population who are long-term sick as the two most important variables to describe the people vulnerability of an area. Section 7.4.1 described why these two variables might be less valid in the wider European context, where the severity of flooding could mean that everyone would be vulnerable if they found themselves in direct contact with the floodwaters. The correlations undertaken by this study confirm this assumption with relation to the percentage of the population who have a long-term illness, as there was found to be no statistically significant relationship between the numbers of fatalities and this variable.

An interesting relationship however was discovered between the numbers of people who died and the percentage of the population who were over the age of 75 years. There is a negative relationship between the number of fatalities and the percentage of the population over 75 years of age. That is, the higher the percentage of those over 75, the fewer the people who are killed in the flooding. This is opposite to the relationship originally described in the *Risk to People* methodology whereby the higher the percentage of people over the age of 75, the more vulnerable the population was thought to be and therefore the higher the number of fatalities.

This last relationship was mainly seen in the samples that did not include the original UK data; thereby indicating that it is only significant when the European events were examined. The only other set of data where it was significant was when only the events where there were deaths were examined. The relationship between fatalities and percentage of the population over 75 years was strongest when only the events where people had been killed by flooding was examined; where the relationship ranged from -0.424 (p-value 0.071) to -0.470 (p-value 0.077).

A clear explanation for this relationship cannot be stated with any certainty, although there are a number of factors that are potentially present in the European context which may explain this relationship. The analysis of the circumstances surrounding death discussed in Section 5.2.2 highlighted that those over the age of 75 years were most likely to be at risk of death from flooding when inside their properties. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain at home or inside. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may indeed be a safer option.

Another relevant factor that appears to be significant is another strong relationship involving the percentage of the population over 75 years of age present within the data. There is a very strong positive relationship between people aged over 75 and the percentage of the population who are evacuated prior to a flooding event. That is, the more people who are over the age of 75 are present within the population, the higher the percentage of the population who evacuated prior to the flood. It must be remembered that although there is a very strong positive correlation (0.769 when the sample includes just the events where there were deaths minus the Czech cases) and a high-level of statistical significance (for the correlation stated the p-value is 0.001) this does not imply a causation between these two variables, i.e. that those people being evacuated are the more vulnerable elderly population. This would need to be investigated in more depth to see if there is a negative relationship between the percentage of those over the age of 75 and the number of people who died during flooding because they had been evacuated from the area. It should be acknowledged however, that within the data collected there are few examples from slow-rise, very long duration floods. It is in these instances where the people vulnerability variables are likely to be more significant. Therefore, if further analysis was able to be conducted on more of these types of events, a clearer indication of the importance of people vulnerability to the assessment of risk to life in Europe might emerge.

8.5.3 Population at risk

A variable that appears in many other models to be important to assessing risk to life from flooding is the number of people exposed to the hazardous event (Brown and Graham, 1988; Zhai *et al.*, 2006; Jonkman, 2007). This makes obvious sense as the greater the number of people who are exposed to the hazard the greater the number of people who can be injured or killed, and many models perform by the use of a mortality fraction or function (as described in Section 2.4). The relationship between the numbers of people who are killed and Nz (or the population at risk) in the sample of the data that only includes deaths (minus the Czech case studies) is 0.509 (p-value = 0.059). This relationship is sensible, as if there are few people exposed to the hazard the numbers who can be injured and killed by the floodwaters is limited to that number. Therefore, although there was not a strong direct relationship within these data between the numbers of people who died and evacuation, evacuating people prior to the event will have a positive effect on the numbers of people *in situ* and therefore able to be affected by the hazard.

8.5.4 Hazard characteristics

The two other variables that are significant when examining the numbers who are killed during flooding events are the depth and velocity of the flood waters. When the sample of events which had deaths is examined (minus the Czech slower rise events) these two variables are statistically correlated with the numbers of people who were killed. The most significant of these variables within this sample is velocity which has a correlation coefficient of 0.548 (p-value 0.035). The original *Risk to People* methodology also observed that velocity appeared to be the most significant of the hazard characteristics, as in the formula for the hazard rating a coefficient of 0.5 was added to this value. In this sample the relationship between the depth of the flood waters and the numbers of people killed has a Pearson's correlation coefficient of 0.494 (p-value = 0.061).

This analysis of the data identified that there are a number of factors that seem to be significant in estimating the risk to life from flooding. The next stage was to undertake a regression analysis on the data to see whether a regression model could be developed to enable the number of fatalities to be predicted from a particular event.

8.6 Multiple regression

Although multiple regression analysis may reveal relationships between variables, it cannot go so far as to imply whether they are causal relationships. An explanation of causality should be a theoretical or experimental argument rather than a statistical one.

Tabachnick and Fidell (2007) argue that regression is best undertaken when each of the independent variables is strongly correlated with the dependent variable (which in the case of this analysis is the numbers of people who die within a flood event) but also uncorrelated with the other independent variables. This may be a problematic factor when considering undertaking multiple regressions on these data as the correlation matrices tables summarised in Appendix F show. The first issue is whether the relationships between the actual numbers of people who died are sufficiently strong to be able to develop a meaningful model. The second factor is the presence of multicolinearity in the data, i.e. there are a number of variables present within the data that have strong relationships to other variables. The most important of this appears to be depth/velocity which are both considered to be important variables for predicting the numbers of people who die from flooding, as described above, and have a strong positive relationship with each other. Therefore, either depth or velocity should be included within the analysis as individual variables (i.e. only one of these variables should be included) or they should be included as a combined factor.

A number of different variations on the depth velocity relationship were investigated, however the most straightforward and effective of which was the product of depth and velocity (e.g. depth multiplied by velocity) which appears not only to be relevant here but has also been applied in other models of this type (e.g. Zhai *et al*., 2006) and as the basis of a number of studies investigating the stability of humans, buildings and cars during flooding (e.g. Abt *et al.,* 1989; Karvonen *et al.,* 2000; Reiter 2000; Lind *et al*., 2004) . In addition, due to the problems described above, this analysis has only been performed on the European events without the Czech data, therefore it should be stated that it is only valid for events of fast and medium onset.

Following a stepwise regression analysis of all European flood zones (except for the Czech case studies), linear regression was conducted on the most significant variables; the population at risk from flooding, the depth velocity product and the scale expressing the awareness of flood risk. The resultant linear equation, shown in Figure 8.3 is based on 31 flood zones which have a total number of 40 deaths.

Numbers of deaths = 2.37 +0.000338N(z) + 0.0525DV - 0.957A
where, N(z) is the population at risk from flooding, DV is the depth velocity product A is the scale of awareness of flood risk

Figure 8.3: Regression equation [1] for predicting flood deaths in European flood events

The r-squared value of this equation is 0.496 and it has an r-squared (adjusted) value of 0.44, the residual plots for this analysis is shown in Figure 8.4. In this equation the factor describing the awareness of the flood risk is negative, however as the scale indicates that a value of 1 is given to an area of high flood risk awareness and 3 is given to an area of low risk awareness, then the equation does appear to be logically incorporating this variable. From the analysis, there appeared only to be one major outlier from the event Duszniki Zdroj Zone C which has a large standardised residual (3.58). It is unclear why this event is not conforming to the model although it should be noted that additional information about the circumstances surrounding the deaths of the seven individuals in this event (other than that they drowned) has not been available. Therefore it is difficult to assess whether there were any unusual or atypical factors leading to these deaths.

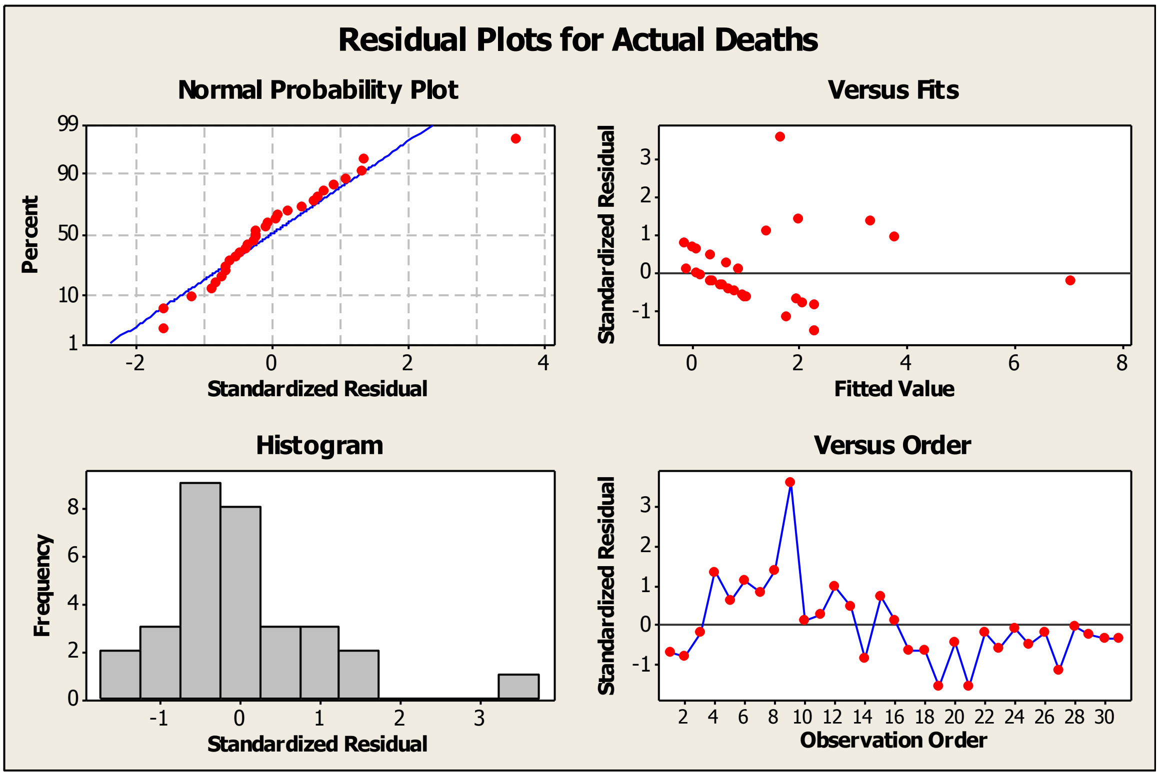


Figure 8.4: Residual plots for the regression analysis [1]

Similar stepwise regression analysis was performed on only those 15 European flood zones (i.e. n=15 and deaths=40) where deaths were present (except the Czech cases) to see whether the data performed differently under linear regression. Similar variables appeared to be significant, although generally to higher levels of significance. Initially the same three variables above were used to create a regression equation, however the variable of the *awareness of flood risk* no longer appeared to be statistically significant (its p-value increased from 0.047 in the first equation to 0.421 in this second sample). Therefore, linear regression was performed again without this variable, using only N(z) and the depth velocity product. This regression equation is displayed in Figure 8.5; its r-squared value increases to 0.590 and the r-squared (adjusted) value to 0.521 with the residual plots illustrated by Figure 8.6.

Numbers of deaths = 0.602 +0.00250N(z) + 0.0706DV

where,
N(z) is the population at risk from flooding,
DV is the depth velocity product

Figure 8.5: Regression equation [2] for predicting flood deaths in European flood events

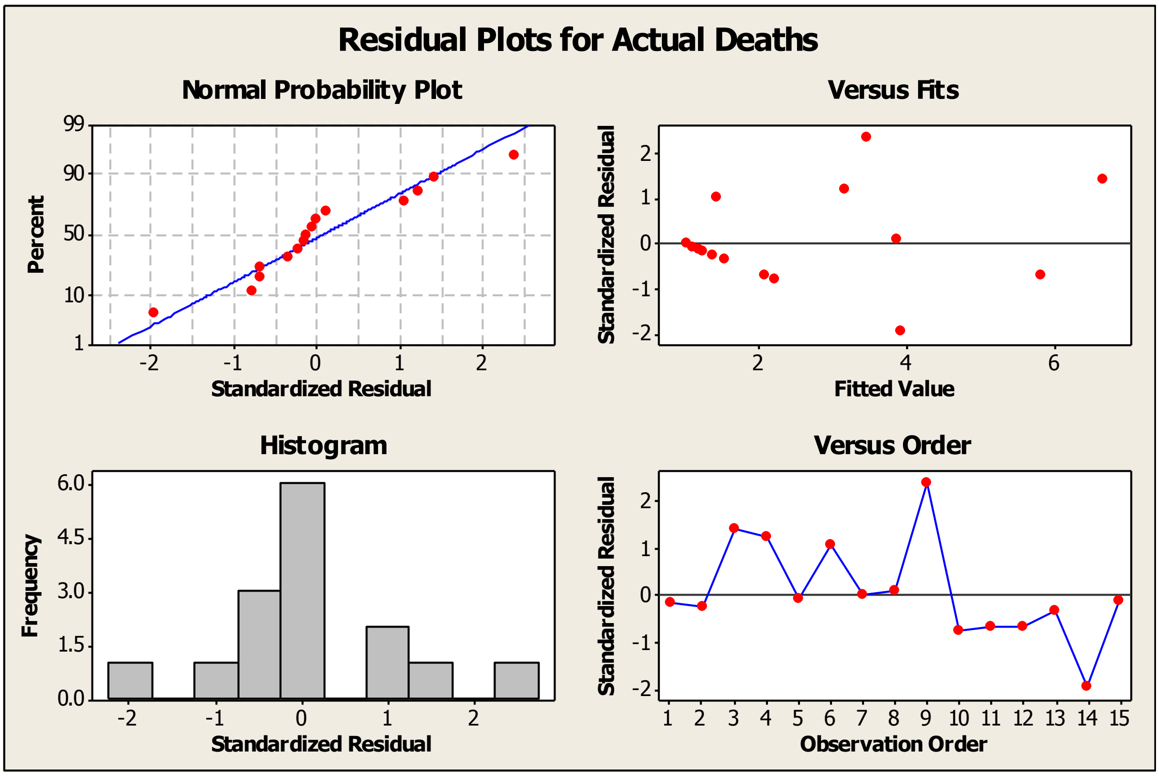


Figure 8.6: Residual plots for the regression analysis [2]

Similar to the first regression equation, Duszniki Zdroj Zone C appears to be an outlying event with a large standardised residual although it does reduce to 2.38. Despite changes in the coefficients describing each of the variables, their relative importance in the equation remains similar. Despite this it is important to question the value of the output of a multiple regression analysis.

The benefit of a regression equation is that it will permit the estimation of the number of people who are at risk from flooding from a particular event or under different circumstances. A regression equation of this nature, although providing an initial indication of the factors important to predicting the numbers of deaths, will be inherently vulnerable to the addition of new data. This can be seen as both an opportunity and a threat, as although the coefficients in the equation will be changed (and therefore any work or assessment undertaken on the basis of this equation might need to be revisited) refinement of the model will be relatively straightforward. This equation is particularly vulnerable as data has been scarce and therefore refinement of any empirical model is recommended. Much more data on a range of different events of flooding with a range of flooding types and flooding outcomes (e.g. with high numbers of deaths, low numbers of deaths and events where there were no fatalities) is required in order to develop and fully calibrate a model of this kind. This is going to be difficult whilst the data collected and archived in European flooding events is so poor.

The equation is incredibly sensitive to the combination of variables included within it. For instance, if a particular flood by chance had a large number of people who died by some mechanism that is not represented, then the model will under predict the numbers of people who will be killed (e.g. from electrocution when flood waters submerge power cables, which is suggested by Jonkman and Kelman, (2005) and Poole and Hogan (2007) as a major cause of death from flooding).

Additionally, the complexity of flooding events observed in Europe and the large amount of variation that occurs (e.g. the great differences in the percentage of the populations that are killed and by different mechanisms) questions the sense of producing an equation of this nature. Pragmatically, an estimation of this nature is likely to be used in advance of a flood event to make some assessment of the potential threat to life from flooding within an area, similar to the approach that the Environment Agency in the UK has taken in their rapid response catchment work (Environment Agency, *forthcoming*). It has been demonstrated (in Section 6) and acknowledged that the original *Risk to People* methodology and also any empirical equation derived (in this research or elsewhere), is going to be very heavily dependent on the data provided. It is also acknowledged that some of these data (such as the population at risk, effectiveness of flood warning) are also vulnerable to large fluctuations based on certain aspects such as time of day, day of the week, availability of people to receive and respond to a flood warning. These fluctuations in some of the basic variables mean that a model which requires quite precise numbers for some of the variables, and that has a single figure output (rather than a range), is in danger of over or under-predicting by large amounts.

8.7 Recommendations for the UK Risk to People methodology

Thus changes to the model were guided by the sensitivity analysis (Section 7.2) and the statistical analyses described above. The sensitivity analysis determined how much influence the model components had on the model results and this, in turn, determined the type of amendment made to the model. For instance, the sensitivity analysis illustrated that Area Vulnerability had the smallest effect on the outcomes so the amendments described sought ways of increasing the effect of this parameter. The People Vulnerability component was shown to have a strong (and potentially destabilising) influence on model outcomes and so the amendments were geared towards reducing its effect and thus its potential to trigger model instability. The statistical analysis determined which cases were included in the revised model. The Czech case studies, for instance, were not included because the flood characteristics were significantly different to the other case studies. In addition, we also attempted to account for the effects of evacuation by subtracting evacuation figures (where these were available) from the Nz value. However, this amendment had no significant effect on the model predictions and the results are not included here.

Some amendments were more successful than others. The most promising amendment to the formula was to convert the PV percentage to an absolute value and then use the reciprocal of this in the calculation (Table 8.10). However, good quality data from many more case studies would be necessary to evaluate the usefulness of this, and other, formula modifications.

As mentioned from the outset, there are a number of variables of importance that the *Risk to People* model does not consider; such as building collapse and evacuation. However, in most UK events these appear of limited importance. One aspect that has not really been incorporated but was fundamental in the Boscastle situation is the impact of search and rescue on the outcome of an event and the number of fatalities. In addition to missing variables, some components of the model appear to function better than others, for instance as discussed in Section 3.6 the Environment Agency have little confidence in the function of the *debris factor* within the equation (Environment Agency, pers. comm.).

However, the model has only really been tested and calibrated on a small number of case studies, many of which occurred a number of years ago since when there have since been major advances in flood warning, communication technologies and changes to search and rescue practices. The case studies used to calibrate and test the approach are all quite severe flooding; the approach has also not really been tested on more minor flooding cases in the UK. Similarly, due to the nature of the data supplied it has not been possible to test this approach with Continental European flooding of a similar magnitude and type to that of the UK. If data could be found for these types of events, it may be found that this approach performs much better and could be applied in these circumstances.

The following Section will therefore introduce an alternative 'threshold' approach to modelling risk to life that simply focuses on the variables identified as the most significant; that is depth and velocity of the floodwaters, and the exposed population (including mitigating variables that might impact upon the numbers of people exposed to flooding).

9. Proposed European Risk to Life model

This Section explores the development of a 'threshold' approach to the assessment of risk to life in Europe. The aim is to combine information on the factors considered to be the most significant when estimating risk to life with other empirical evidence and theoretical knowledge to develop a simple 'banded' or threshold approach to risk to life assessment.

9.1 Conceptual model

At the highest level, the theory explored within the original risk to life model is still applicable to the situation in Europe (Figure 9.1).

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

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 9.1: 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 9.2).

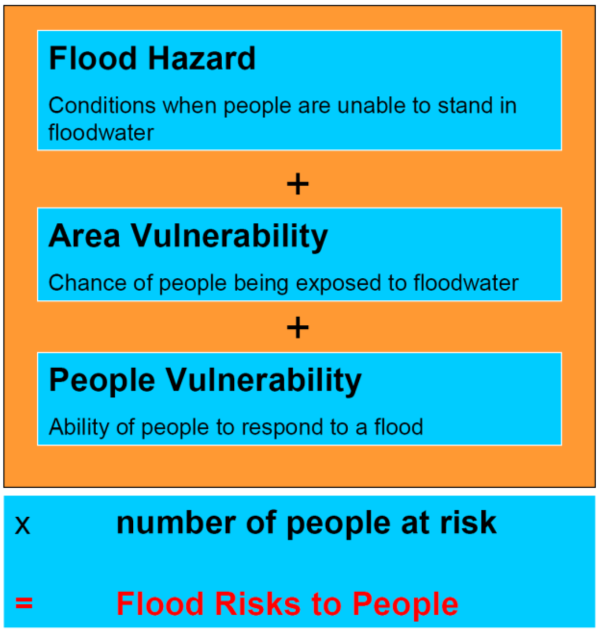


Figure 9.2: Method for calculating flood risks to people

HR Wallingford (2005c, p2)

However, according to the previous analyses of the situation within other parts of Europe this does not really fully explain the situation leading to risk to life from flooding. For instance, although people vulnerability is important at lower flood depths and velocities, it is less important in some of the more risky situations in Europe where the floods are severe enough to threaten most or all of the people who are in direct contact with the flood waters. This was seen in the dataset collected as part of this project which mainly consisted of often deep and fast flowing waters. In addition, the flood hazard component in this model excludes the role of building collapses on the eventual numbers of people who are fatally injured by flood waters. As explained previously this was the main cause of fatalities in a number of case studies and if it occurs is a significant threat to life. The role of evacuation (either formally organised or informally undertaken) and its positive impact upon the numbers of people who are exposed to the hazard is also not really considered within the *Risk to People* methodology. This is likely to be a consequence of the fact that in the UK planned evacuation from flooding events is very rarely necessary. Although Figure 9.3 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.

$$\text{Risk to Life in Europe} = f(\text{F}, \text{E}_x, \text{P}_v, -\text{M})$$

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 9.3: Proposed conceptual model for assessing risk to life

9.2 Hazard factors

From the statistical analyses undertaken as part of this project and from other studies investigating the potential number of lives lost from flooding, the most important factors are flood depth and velocity and it is these hazard factors that will first be considered. A number of studies have explored the notion of human stability in flowing water which is described in Table 9.1. Each of the studies has in their different ways attempted to identify those speeds and depths where human safety is compromised. It must be noted from the outset that this is a very difficult undertaking as each individual may differ, as a person's ability to withstand flood water is dependent on such factors as their height, weight, age and physical condition. Lind *et al.* (2004) have identified that the drag on a person in the water also contributes to their instability in flood waters. In their study they argue that this drag is determined by the clothing that they are wearing, as generally those who are wearing bulkier clothing will experience more drag in the water. Additionally, a person's ability to remain stable in flood waters may also be affected by other environmental conditions such as whether there is good visibility, the temperature of the water and the presence or absence of debris. Despite there being obvious differences in people's ability to maintain stability and safety during flooding, it is possible to identify broad thresholds at which flood waters will become dangerous to people. First it is necessary to consider how depth and velocity should be represented.

Many of the studies have used the product number of depth multiplied by velocity as a function to describe when human stability is compromised. Although as described above it is difficult to quantify the thresholds, Abt *et al.* (1989) argue that the product number can be used as a rough indicator or predictor of when a human would become unstable in flood waters. However, HR Wallingford (2003) argue that velocity is more important than depth and offer the alternative equation *depth x (velocity + 0.5)* as they argue that this offers a better estimation of the hazard to people. Using this formula, Figure 9.4 identifies thresholds where different individuals are in danger from the flood waters, based on their height and weight. The resulting thresholds are displayed in Table 9.2.

Table 9.1: Studies that have investigated the human stability in flowing water

Study	Variables	Instability values / thresholds	Description
Abt *et al.* (1989)	Product number = depth x velocity	The average product number where people will become unstable is at 11.7 ft^2/s. ($1.09m^2/s$) However, it is acknowledged that the results vary according to height, weight and physical condition.	Used a flume experiment to identify the flows humans could withstand. Alongside a control experiment with a monolith, a range of people were assessed with a mix of ages and gender, the slope of the bed was also altered alongside the bed material. Subjects were subject to incrementally increasing flows until they reported a loss of stability or manoeuvrability. The findings indicated that the product number was larger for the people than the monolith slab as people are able to adjust their body stance and position to adjust for the flow conditions. This study has a range of limitations; the study was undertaken in controlled conditions and therefore it was argued that as the subjects were studied a number of times they were able to gain experience of the procedure, they may have gained extra confidence from the fact that they had good lighting and safety equipment and therefore sustained higher flows than in flood conditions.
Karvonen *et al.* (2000)	Product number Depth x velocity	Product numbers where stability was lost ranged from 0.64 m^2s to $1.26m^2s$. The average was 0.96 m^2s. *Equations of human stability offered.* Good conditions vd<0.006hm+0.3 Poor conditions vd<0.002hm+0.1 where h=height of the subject in metres and m = weight of the subject in kg.	This report describes physical experiments undertaken on seven people (of varying heights and weights) in controlled conditions within a flume-type experiment and recorded loss of manoeuvrability and/or stability under a range of depths and flows. The depths ranged from 0.3-1.1 m and the flows 0.6 - 2.75m/s and it was recorded not surprisingly that taller and heavier individuals coped better with the flowing water. The product number causing loss of manoeuvrability or stability varied from 0.64 m^2s to $1.26m^2s$. This report offers two different equations based on the product of weight and height. The first is for human stability in good conditions (i.e. when the underfoot conditions are good, the water is warm with no debris, the subject is in good health and has no other load, and there is good viability and good lighting). The equation for poor conditions should be used most often as these are the conditions more likely during flooding. This study argues that these equations provide lower results than Abt *et al*. 1989. One potential reason for this is the participants were wearing heavy and bulky dry suits which makes it harder for people to manoeuvre and increases their surface area.

Study	Variables	Instability values / thresholds	Description
Lind *et al.* (2004)	Depth x velocity	All observations of when using the simplest model (which is merely to use the depth-velocity product) range from 0.65 to 2.13m^2/s. With the mean of the sample being 1.22 m^2/s.	This study investigates hydrodynamic models of human stability in flooding. Lind *et al.* argue in their analysis that the important variables affecting human stability are the product number e.g. depth * velocity and the drag, which is dependent on the clothing the person is wearing. They discuss the need to disaggregate the dataset into males and females and then into those who are lightly clad as opposed to those who are wearing many layers of clothing. The authors have developed, investigated and calibrated (using the experiments undertaken in Abt *et al.*, (1989) and Karvonen et al. (2000)) four possible variations investigating factors including water depth, veloicty, height and weight, but recommend use of the simplest relationship (except for some subpopulations such as children) due to the inherent uncertainties associated with flood analysis.
Jonkman *et al.* (2005)	Depth x velocity	People become unstable between the range from 0.6 to 2 m^2/s.	Jonkman *et al.* provide a physical interpretation of human stability in flowing water. They have taken the values found in other experiments, and this study verifies that these estimates are reasonable from a physical perspective.
HR Wallingford (2003, 2005a)	Depth (velocity + coefficient) Depth (velocity + 0.5)	<0.75 m^2/s Low 0.75-1.25 m^2/s Moderate 1.25-2.5 m^2/s Significant >2.5 m^2/s Extreme	HR Wallingford *et al.* have taken the information from previous studies and have gone one step further to identify potential thresholds for different members of the floodplain community. This analysis and these thresholds can be seen in Figure 9.4 and Table 9.2. They concluded that since velocity was a more important variable than depth a coefficient needed to be introduced to the product number to reflect this.
Jonkman and Penning-Rowsell (forthcoming)	Depth x velocity	The depth-velocity product (*hv*) has a physical relationship with moment instability whereas friction instability is more closely related to the hv^2 product. Instability is said to occur at around half the depths given by Abt et *al*. (1989) for the velocities encountered.	This study adds further experimental data to previously published literature. It draws on a river experiment designed to replicate as closely as possible a real-world situation and uses a professional stuntman as a 'victim.' He was unsupported by safety ropes (although rescue was in place downstream from the experiment) and the velocities and depths were altered using sluice gates into a relief channel of the River Lea, UK. The experiment was conducted for both standing and walking situations.

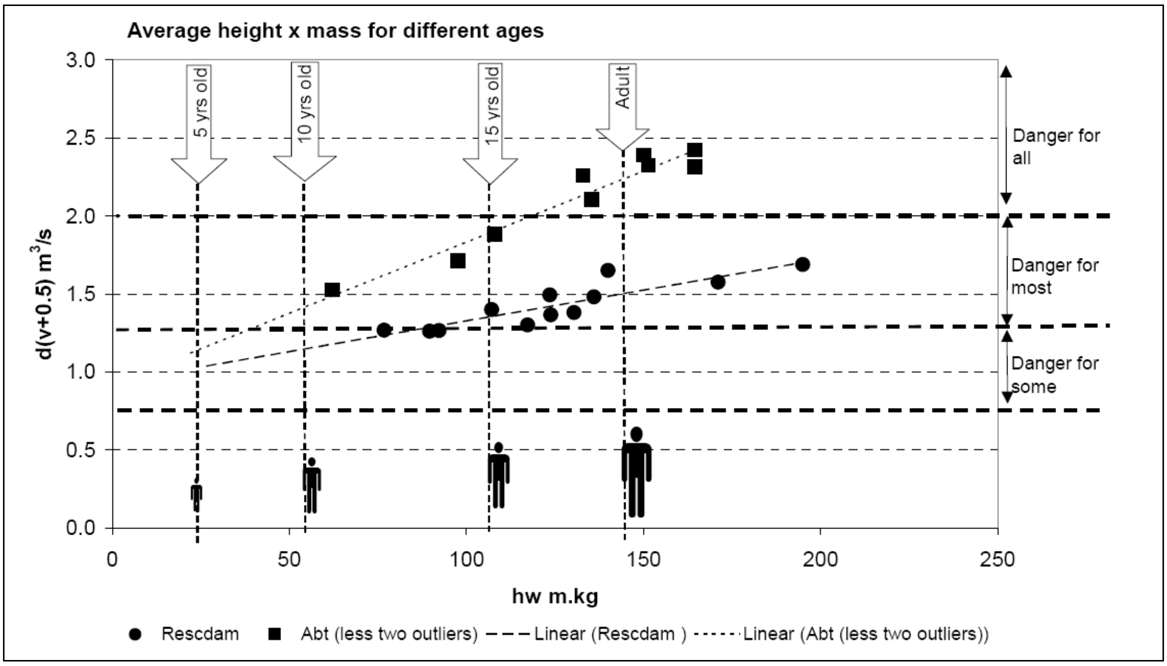


Figure 9.4: Loss of stability figures taken from Abt et al. (1989) and Karvonen et al. (2000)[11]

Source: HR Wallingford (2005, p7).

Table 9.2: Flood hazard thresholds as a function of depth and velocity

d x (v + 0.5) (m^2/s)	**Degree of flood hazard**	**Description**
<0.75	Low	Caution *"Flood zone with shallow flooding water or deep standing water"*
0.75 – 1.25	Moderate	Dangerous for some (e.g. children) *"Danger: Flood zone with deep or fast flowing water"*
1.25 – 2.50	Significant	Dangerous for most people *"Danger: Flood zone with deep fast flowing water"*
>2.50	Extreme	Dangerous for all *"Extreme danger: Flood zone with deep fast flowing water"*

Source: HR Wallingford (2005, p8).

In addition to the assumption that some people will be outside, the model developed will include other locations where people may be during flooding; either through chance or through seeking shelter. It is therefore necessary to identify similar thresholds for a *depth x velocity* function for features such as motor vehicles and buildings. After re-plotting the results found in both Karvonen *et al*. (2000) and Abt *et al.* (1989), and adopting the approach undertaken in HR Wallingford (2005a), Figure 9.5 calculates the depth-velocity function for each variable and identifies potential new thresholds based on a depth-velocity product.

[11] The estimates of the heights and weights illustrated in this graph were based on figures taken from UK Department of Health data with average figures.

		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 9.5: 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. Indeed, as illustrated in Table 9.1 above, 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 9.3, presenting a low, mid, high and extreme estimate to all of the thresholds.

Table 9.3: 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 (e.g. 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).

9.3 People exposure

The analysis above indicates the potential risk to human stability from flood waters. However not everyone will be outside during a flood; some people will be inside or will seek shelter from direct contact with the floodwaters. For instance, people who are located in a well-constructed three storey building made of bricks are likely to be less exposed or vulnerable to the threats of flood waters, than those who are staying in mobile accommodation. As discussed in Section 2.3.5, those people in vehicles may be exposed and thus vulnerable to flooding. Motor vehicles can become unstable in quite shallow waters. Reiter (2000) (taken from the RESCDAM work) suggests ranges for the risk and damages that can occur to personal vehicles. Although these have been applied within a dam break analysis these are still useful and relevant when considering other types of flooding. These thresholds can be seen in Table 9.4.

Table 9.4: Critical parameters for damage to motor vehicles applied to dam break flooding

Risk of damage	Damage parameter (depth x velocity) m^2/s		
	Small damages, small danger	Medium damages, Medium danger	Total damages, very high danger
Personal cars	< 0.3	0.50 - 0.60	> 0.6

Source: Reiter (2000, p11).

9.3.1 Vulnerability of areas

It is necessary to identify those locations which will have a higher degree of vulnerability than others, either by their character or by the presence of a large number of vulnerable people (e.g. children and/or elderly or sick people). For instance areas with campsites, locations of mobile properties or areas with large open recreational spaces will provide little shelter from direct contact with flood waters. Urban residential areas or other locations with buildings should in theory provide a higher level of shelter from flood waters, although the degree of this will vary according to the building type, the quality of construction and the number of storeys that a property has. However, in severe flooding the integrity of this shelter may be compromised by either structural damages or in some instances total collapse. It is therefore necessary to comment upon the resistance of buildings to flood waters.

9.3.2 Building integrity and collapse

There are a number of factors to consider when attempting to place thresholds on the ability of a building to withstand floodwaters. These include the materials that the building is made from (e.g. timber, brick, stone or a mix of materials), the quality of the original construction, construction methods, the age and condition of the property. These variables make it very difficult to put exact thresholds on building collapse and therefore those described below are only broad guidelines. It is recommended that if the model developed here is applied to a specific location, these thresholds be altered to reflect the local style and nature of the building fabric.

A number of different studies have investigated the integrity of buildings to flood waters (Clausen 1989; Karvonen *et al.*, 2000; Roos, 2003; Kelman and Spence, 2004). This study adopts the thresholds developed by Karvonen *et al.* (2000) which identified different depth velocity product thresholds (see Table 9.5) for partial and total damage of three types of properties; wooden (unanchored), wooden (anchored) and masonry concrete and brick. For masonry, concrete and brick buildings there is a velocity threshold (of >2m/s) which is also significant to the onset of structural damages.

It is interesting to look at these thresholds in the context of the European flood events that have been studied in this report. Building damage has not been recorded in all cases but the numbers of buildings or structures (such as bridges or roads) that suffered collapse has been identified. Of the 52 deaths recorded 11 were caused by properties either partially or fully collapsing, whereas a further 7 deaths were caused by the collapse of roads or bridges, see Table 9.6.

Table 9.5: Flood conditions leading to the partial or total damage of buildings in Finland

House type	Partial damage	Total damage
	vd = velocity x depth	
Wood framed- unanchored	$vd \geq 2$ m^2/s	$vd \geq 3$ m^2/s
Wood framed-anchored	$vd \geq 3$ m^2/s	$vd \geq 7$ m^2/s
Masonry, concrete and brick	$v \geq 2$ m/s and $vd \geq 3$ m^2/s	$v \geq 2$ m/s and $vd \geq 7$ m^2/s

Source: Karvonen *et al.* (2000, p18).

In most cases the buildings do appear to be collapsing under the situations explained above, although the relationship between the depth-velocity product and structural collapse appears to be very complex as there are a number of anomalous events. Half of the events studied had properties or bridges that totally collapsed, most of these did have values that were greater than the suggested depth-velocity product of greater than or equal to 7m^2/s by Karvonen *et al.* (2000). Additionally, there were a number of events that also had a depth velocity product number greater than 7m^2/s, yet no building collapses were reported. This does not necessary mean that the threshold levels chosen are incorrect; merely that buildings might not always be completely destroyed or even that total collapses are not accurately reported. A further reason for this might be related to the depths and velocities reported within the hazard zone, as discussed previously (Section 4.4). In some cases these values are potentially the highest values and therefore not all buildings will be equally exposed to these severe levels. Moreover, if it is an urban area that is affected not all of the buildings will be equally exposed to the same flood depths and velocities; some buildings may have a sheltering or shadowing affect on other buildings, reducing the severity of the depth-velocity value that they experience.

There are also a couple of anomalous events where the depths and velocities were relatively low yet there were many buildings that collapsed. These events, Troubky and Olomouc, are both categorised as slow rise floods and both zones are found within the Czech Republic. In both of these events hundreds of buildings collapsed (337 and 208 respectively). In this situation it appears to be building materials and construction that are to blame for the high level of building collapse in this region. It was reported that the majority of the properties in this rural region were constructed cheaply some as long ago as 150 years, out of plaster over unfired brickwork (FLOOD*site partner survey response*).

Table 9.6: Instances of building collapse within the European flood events

Flood event / Hazard [12]Zone	N (Z)	Depth	Velocity	Depth[13] x velocity	No. of collapsed buildings	Other collapsed structures	Total event fatalities	Collapse-related fatalities
Fella a	400	2.5	3	7.5	0 – But 40 homes buried by sediment and almost 100 damaged by the flood waters		1	
Fella b	500	3	3	9	0 – But 250 houses buried by sediments and hundreds more damaged		1	
Cassano Murge	20000	3	5	15	0	Collapses of roads and railways.	**7**	5 members of the same family swept away in their car when crossing a bridge that collapsed;
Fortezza	60	4	9	36	0	Collapses of roads and railways.	5	
Calonge	1300	1	2.5	2.5	0		1	
Cambrils	2000	3	1.5	4.5	0		3	
La Farinera	200	2	2.5	5	1	Two small bridges were reported to have collapsed	1	
Magarola	300	5	9	45	0	Bridge collapse	**4**	Two people died in their car when a bridge collapsed. In addition two policemen who went to look for them also perished
Duszniki zdroj zone c	120	4	10	40	0		7	
Klodzko gmina zone c	1050	3.8	5	19	4		1	
Klodzko town zone a	200	4	5	20	0		1	
Klodzko town zone c	2500	6.5	10	65	5		5	
Miedzylesie zone b	876	2	5	10	4		**1**	1 man (34) was sleeping when his bedroom was flooded and collapsed into the floodwaters
Stronie Slaskie zone a	2000	4	10	40	0		1	
Troubky	2010	2	0.3	0.6	337 - 50% of the buildings were destroyed[14]		**9**	All nine died in collapsed buildings
Olomouc	28200	2	0.42	0.84	208 - Most collapsed buildings were made of unfired bricks or a mix of materials		2	
Otrokovice	19000	3.5	0.34	1.19	0 – but 1082 houses were damaged of which 562 were out of use for a long time		1	
Dresden	300	1.8	4	7.2	1 - Around a further 20 buildings that were being constructed were destroyed.		**1**	The loss of life occurred when the building collapsed
Erlin	100	1.6	4	6.4	0		0	
Grimma	1200	3	7	21	50		0	
Eilenburg	275	2	4	8	0		0	
Bystrzyca Klodzka zone a	450	5	10	50	0		0	
Stronie Slaskie zone b	400	2	10	20	0		0	
Polanica Zdroj zone a	420	5	10	50	3		0	
Miedzylesie zone c	138	1.5	10	15	0		0	
Miedzylesie zone a	369	2.5	10	25	1		0	
Ladek Zdroj zone d	300	2	5	10	0		0	
Ladek Zdroj zone b	250	4.6	5	23	0		0	
Ladek Zdroj zone a	180	3	5	15	1		0	
Duszniki zdroj zone b	450	4	10	40	0		0	
Klodzko gmina zone a	120	2	5	10	0		0	
Bystrzyca Klodzka zone b	1050	2	5	10	2		0	
Klodzko town zone d	30	4	5	20	0		0	
Klodzko gmina zone b	100	3.8	5	19	1		0	

[12] The shaded events are those which experienced some property or other structural collapse
[13] These are the events with a depth velocity product score of greater than 7m^{2}s.
[14] The events highlighted in red have high numbers of buildings that collapsed, but with low depths and velocity

During flooding, and in particular severe flooding, where possible the majority of people will try to shelter from the flood waters in buildings. Buildings however, will obviously withstand higher depths and velocities than individuals, as well as modifying the descriptions of other hazard levels it is 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 > $7m^2/s$ where all buildings that are in direct contact with the flood waters are vulnerable (assuming that velocity ≥ 2m/s) is added in Table 9.7.

Table 9.7: 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 (e.g. 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 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).

Table 9.8 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.

Table 9.8: 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.

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).

9.4 Risk to Life from flooding

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 9.6 combines the thresholds for people directly exposed to the flood waters and the information about whether particular areas are vulnerable and illustrates these thresholds and identifies the risks associated with flood waters at each of the different levels. The model provides three 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 9.9. and Figure 9.6, 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.

Table 9.9: 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		

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.

DEPTH x VELOCITY MID-RANGE	OUTDOOR HAZARD	NATURE OF THE AREA	STRUCTURAL DAMAGE	RISK TO LIFE FROM FLOODING	FATALITY FACTOR
$>7 m^2s^{-1}$	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 9.6: First half of threshold model indicating the risk of life from flooding

9.5 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.

In many instances in Europe, evacuation is a real and important option that is used to mitigate against the worst flood events. Indeed, half of the flood events studied in this report (n=17) had some level of official evacuation taking place either before, during or following the onset of flooding, although the numbers of people that were evacuated varied from 2% of the population (in Olomouc, Czech Republic) to over 95% of the population (in Eilenburg, Germany). Official evacuation levels will no doubt be affected by the lead time before the warning, but may also be impacted by other variables such as previous experience of flooding, levels of trust not only in the forecast but also in that their property will not be looted, as well as the availability of a flood-free route out of the danger zone. Self-evacuation levels may also depend upon previous experience of the hazard, availability of transport and knowledge of a flood-free route. In this first iteration of the model two levels for evacuation are presented: full and partial.

Obviously, in the situation where all (or close to all) of the population at risk is moved from the situation the level of risk will be reduced as there will be no (or few) people left for the flooding to impact. When adapting and developing the model further or tailoring it for a specific region, the evacuation component might be split into more categories and rough percentages given for each (e.g. <25% evacuated, 25-50% evacuated, 50-75% evacuated or >75% evacuated) thus providing an extra level of detail.

In situations other than evacuation, the mitigating action undertaken may still mean that large numbers of people are still in the area of the hazard, but are not necessarily exposed. In other, less severe, circumstances an effective flood warning with a longer lead time will be sufficient to allow people to get out of direct contact with the flood waters and then potentially reduce their chances of being injured or killed. The effectiveness of this shelter however, is also related to the severity of the depths and velocities experienced and the structural integrity of the properties. For instance, in the situation whereby the most extreme hazard is experienced (i.e. where depth-velocity is $>7m^2/s$) all those remaining in the area will be exposed to the possibility of partial or total collapse of buildings. However despite the threat of structural collapse people are still likely to be safer sheltering in buildings rather than exposing themselves to the flood waters. In other situations however, the speed of onset might be such that a flood warning is not possible or there may be areas where flood warnings are not available, not effective or are too late to provide people with the options of taking action. To represent this type of situation two more categories have been added to the model: *no flood warning available or a short lead time* and *effective flood warning with adequate lead time.*

Table 9.10 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. In this instance these broad categories will indicate the principles or the methodology and can be used at a broad scale to highlight whether the risk category explained in Sections 9.3 and 9.4 is realistic to the area, or whether official flood response measures will reduce these categories. 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 9.10: 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. Thereby 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.

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

Figure 9.7 combines the hazard and exposure thresholds illustrated in Table 9.7 and the mitigating factors to provide a 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 in Figure 9.7 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 over the methodology applied in the *Risk to People* methodology (which is best illustrated in Section 11 when looking at risk mapping), 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[15]	**OUTDOOR HAZARD**	**NATURE OF THE AREA (VULNERABILITY)**	**STRUCTURAL DAMAGES**	**RISK TO LIFE CATEGORIES WITHOUT MITIGATION**	**MAIN FACTOR LEADING TO FATALITIES**	**MITIGATION FACTOR[16]**	**RISK TO LIFE WITH ACTIONS**	**ACTIONS[17]**
$>7 m^2s^{-1}$	Extreme Dangerous for all	**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)	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.
						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.
						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 9.7: Threshold approach to assessing Risk to Life from flooding in Europe

Key

Extreme Risk | High Risk | Moderate Risk | Low Risk

[15] The mid-range values are presented here. See Sections 9.2 and 9.3 for an explanation of the ranges of hazard variables.
[16] Four different mitigation variables are presented in the model. See Section 9.5 for a description of how these might be tailored to specific location or scenario.
[17] The actions provided here are indicative. If possible, these should be tailored to the local situation and circumstances.

9.7 Application of the proposed European Risk to Life model to the European flood event data

The new model has mainly been developed to assess the risk to life from flooding in an area. Figure 9.7 should be used 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 (Section 9.3.2). 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. A range of different types of flooding events and events of different outcomes is illustrated in Table 9.11.

Table 9.11: 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.
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 medium 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

Although the approach is highlighting the severity of flooding experienced, it has been difficult to test whether the approach is differentiating between events, as the data that has been collected as part of this study are some of the worst floods experienced in Europe over the last two decades. The approach needs further testing on events of many different magnitudes. Similar to the limitations of the *Risk to People* methodology, this approach cannot take account of chance or all actions that people undertake during flooding.

9.8 Discussion and recommendations

This model has been designed to make an initial qualitative assessment of risk to life from flooding events in Europe. It has been developed to be flexible enough to be used and applied at a range of scales, for instance for a broad assessment at a regional or national scale, or to be applied in more detail at a higher resolution.

The results generated from the application of this approach are, similar to other models of this type, sensitive to the data input into the model. However, the 'banded' or scale approach adopted does permit some scope for uncertainty, in particular within the depth and velocity data. However, the model will of course be most sensitive to error at the thresholds of the different depth-velocity product classes. When applying the qualitative model at a high resolution, it is also recommended that users of this approach use the approach iteratively, using their own knowledge and experience to tailor the categories and what they contain to their local situation. For instance, if a user recognises that their region has a very high proportion of timber buildings, which from experience it is understood that they can only withstand a depth-velocity product of 3 m^2/s, then it would be rational to replace the highest threshold of 7m^2/s and adopt the lower value where the majority of properties are threatened and therefore people exposed.

The comments suggesting how resources should be targeted are also only a guideline and flood managers and emergency responders should identify their own priorities for action, making best use of the resources at their disposal. It is recognised that flooding can occur on a wide scale therefore stretching, what are in some cases, limited resources and personnel. For instance, the Czech flooding of 1997 and 2002 covered large areas of the country (11, 000km^2 and 17, 000km^2 respectively) and also affected large numbers of the population (63% and 66%) so responding to flooding on this scale will be difficult (Hladný *et al.*, 2004). Therefore, different zones should not be examined in isolation, but their risk assessed and the outcome integrated into a comprehensive action plan.

It is acknowledged that it is difficult to estimate the risk to life from flood events and it is also recognised that the 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. The following Section will demonstrate the use of this approach within a mapping methodology and provide case study illustrations of its capacity to assess risk to life from flooding.

10. Mapping risk to life

10.1 Past and current approaches

Thanks to the development of Geographic Information Systems (GIS) and the recent increase of available spatial data on the web, mapping has become more accessible. Mapping is a good tool to share information and to support decision processes in a large number of domains. But as it is mainly a tool, the basis of any mapping is above all the methodology behind it. It is useful to begin with some basic definitions of what is risk to life mapping. Risk mapping is the process of establishing the spatial extent of a risk, i.e. information on probabilities and consequences of an event. Risk mapping requires combining maps of hazards and vulnerabilities (Gouldby *et al*., 2005). Thus a flood risk map is more than a simple flood hazard map. Risk assessment is usually presented in the form of maps that show the magnitude and the nature of the risk (Gouldby *et al*., 2005). The magnitude of the risk could be expressed quantitatively, qualitatively or descriptively depending on the model used and the data available. The nature of the risk characterises the kinds of consequences that are analysed. For instance the nature of the risk to life is limited to injuries and fatalities affecting a population. Whatever the nature of the risk, the processing of mapping remains in fact quite similar. In this case GIS is mostly used for post processing of data through reformatting, tabulation, mapping and report generation.

10.1.1 Hazard map

In the FLOODsite project, a Flood Hazard map is defined as a map with the predicted or documented extent of flooding, with or without an indication of the flood probability (Gouldby *et al*., 2005). Merz et *al*. (2007) have produced a recent and complete review on the subject. They actually stress the difference between a flood hazard map and a flow danger map. A flood hazard map shows the spatial distribution of the flood hazard (with intensity and probability) and a flood danger map shows the spatial distribution of the flood without information about the exceedance probability. In this report we will follow this definition and will restrict the risk map to the map with an indication of the flood probability.

Different sources could be used to describe the hazard for a location. The precision and the values brought to the risk model will vary on these maps. Classic maps are existing maps showing the extent of a flood event for a given return period. They may also provide flood depth information. If not, the depth can be estimated with an elevation map. The maps do not usually include information on velocity or other values, and they are thus limited in flood risk mapping which deals with complex processes. An example of their use is shown and how to deal with the lack of data for the Gard river case study discussed below. As already mentioned in this report (section 3.5) one other way to create a hazard map is to use the output of 1D or 2D models. Output from such models could be valuable on flood risk mapping results as they offer a number of advantages. They could provide depth and velocity results but also uncertainty outputs. They allow the testing of different scenarios and the generation of probability maps. Nevertheless, the use of such models needs high expertise and requires a large amount of information and time and can be costly (Merz *et al*., 2007).

A 1D model comprises river or channel hydraulics modelling (network mathematical resolution). These are limited for representing flooding to a large extent. 2D models use a 2-dimensional cell environment (raster mathematical resolution) to represent the spatial extent on a floodplain of an event and offer the advantage of having a full and good spatial representation of an event when calibrated with existing data. Constructions of new flood scenarios are possible with such model, but all extrapolation to a greater event than the one calibrated have to be used carefully. The best approach is to use both 1D and 2D models in a same model. 1D or 2D resolution is used depending on the level of required details from different locations on a map; this saves time, data-requirements and accuracy. Werner (2004) has also shown in a comparison of three specific 1D, 2D and 1D-2D models that the integration of 1D-2D code is the most reliable in extrapolating scenarios. Examples of 1D-2D models are MIKE FLOOD, a dynamically linked one-dimensional (MIKE11) and two-dimensional flood (MIKE22) modeling package[18], INFOWORKS 2D[19] or XP-SWMM and TUFLOW (Phillips *et al.*, 2005). An example of the use of 2D output for Thamesmead is given in Section 11.2.1below.

10.1.2 Vulnerability map

In the FLOODsite project vulnerability is defined as a function of the susceptibility and the value of the receptor or entity that could be harmed. Receptor could be a person, a property, an activity, a habitat etc. (Gouldby *et al*., 2005). Compared to the hazard map, the vulnerability map could support very different types of information depending on the nature of the risk, but it is still an open field. Indeed risk mapping is usually limited to hazard maps, sometimes overlaid with cadastral information. Merz *et al*. (2007) stress the fact that there is a low state of knowledge in flood vulnerability analysis and that the estimation of flood consequences is still in its infancy, as approaches on economic damages, consequences on population or indirect economic losses are largely neglected.

One of the major issues to be solved is the collection of the required data on the study area. Cadastral and land use data are now available in GIS format and give the support for the analysis. But the inherent characteristics of receptors require a long and difficult process of data collection as they are not readily available. One example is the Household Vulnerability Equation. This equation is a function of six ranges of variables (Penning-Rowsell *et al.*, 1994). Two of them are the socio-economic variables and the property and infrastructure variables. The socio-economic variables contain age profile, health status, savings, income, cohesiveness of local community and flood knowledge. The property and infrastructure variables contains the susceptibility and robustness of building contents to damage, susceptibility of building fabric, the time taken to restore infrastructure, and the number of storeys. Some data are confidential which makes it almost impossible to access without detailed local surveys, but they are crucial for any accurate assessment. The knowledge of stakeholders, shared in a participatory process, could also provide a source of information to build the vulnerability map. The use of “cognitive mapping” for instance could allow assessment of the risk and vulnerability perception of end-users on flood events and the collection of qualitative data that are usually not measured during the flood crisis. An example is given in a current FLOOD*site* study, see Lutoff and Ruin (2007).

Flood risk mapping is not limited to a small scale. Large-scale mapping presents an opportunity to compare the risk over a territory (basin, nation, EU) and to have a more integrated approach of flood management. Thus Barredo *et al.* (2007) assess the flood risk mapping at a European scale. The exposure (potential disaster loss) is there defined as a function of population density at NUTS3 level and of the land use potential cost of damage with Corine Land Cover 2000 data. They have also based their vulnerability factor on GDP per capita at NUTS 3 level, the only proxy available for the whole of the EU.

10.1.3 Dynamic mapping

A flood risk map is the combination of a hazard map and a vulnerability map. The combination could be the result of different processes, such as a logical tree process or mathematical equation. As already mentioned, the results could be qualitative, quantitative or descriptive and are available in a raster or vector format (point, line or polygon); they are highly dependant on the risk model that is applied. The maps are also usually static, which means that they only show one moment of the flood event: usually the peak flow or the risk change in intensity and spatially during a flood event. Vulnerability is also affected by the temporal change. Flood risk in the summer or winter or during the camping season will not affect an area in the same way (Merz *et al*., 2007). The fact that the flood, especially a flash-flood, happens during the day or the night, at the weekend, or on a working day has also different effects, as the population is not in the same place or do not demonstrate the same behaviour. By using only one

[18] http://www.dhisoftware.com/mikeflood/
[19] http://www.wallingfordsoftware.com/uk/products/infoworks_cs/infoworks_2d.aspx

map to represent an event, lots of potential information offered by the flooding models is also lost. Therefore the use of models with multiple scenarios could be useful in a risk assessment exercises.

The dynamic of a flood event and the dynamic of human activities results in a change of vulnerability and risk, and these considerations represent two new challenges in flood risk mapping. The first challenge is mainly technical and has an impact on risk communication. By combining data from times-series flood model outputs, from multiple flood event scenarios and from different vulnerability scenario, the resulting databases and map are huge and, at least, difficult to produce as it requires some automatic computing procedures. The large sized map is a problem in risk communication as the end-user cannot deal with all the information. One solution is to produce a dynamic map showing the temporal risk impact of a flood event. End-users also look for different information depending on their function (McCarthy *et al.*, 2007) and sometimes just need an answer to a simple question. To resolve such issues, ZERGER *et al*. (2004) have developed an innovative approach applied to risk of inundation caused by cyclone events. For one cyclone scenario, the model produce 432 raster inundation surfaces for a 72 hour event analysed at 10 minute intervals. To manage the vast geo-temporal data-bases and to provide rapid access for end-user to the model outputs, they have integrated a relational database management system with a GIS. The potential of the tool regarding is that it allows the management of vast databases and the fast production of time-series maps. Through a rapid data query system, the end-user can also interrogate the database based on pre-defined geo-temporal questions. Such systems offer great potential for decision support tools in risk communication.

The second challenge is linked to the representation of human behaviour during a flood event and how it affects the risk to life mapping. Humans are not trees or buildings; they move or adopt different behaviours during a flood event. This behaviour could change their state in a positive way (more safety) or in a negative way (risk of injuries, death). The changing environment (flood) has a great impact on this behaviour. During the Gard flood for instance, some people moved at least once because of the flood event. The main reason is to gather the family and to collect children from school or to help relatives. Unfortunately it usually leads to increased risk as they get close to the flood area (Lutoff and Ruin, 2007). New approaches involving Agent-Based modelling are now emerging in risk to life modelling. Indeed one aspect considered in Agent-Based modelling is that the behaviour of large groups can be understood on the very basis of very simple interaction rules, so that individuals act essentially as automata responding to a few key stimuli in their environment (Ball, 2004). The BC hydro Life Safety model (Johnstone *et al.*, 2005) estimates the loss of life following dam failure based on artificial intelligence. The potential loss of life is dependant of the structural environment (building, outdoor, road), the behaviour of individuals (stay, walk, and use of vehicle), the spatial and temporal dynamic of the inundation, the existing warning and evacuation process. More details on such an approach can be found in the literature for Task 17 of the FLOOD*site* project (Gaume *et al*., 2007).

10.2 Summary

- Risk mapping consists of the combination of hazard maps and vulnerability maps; the output could be qualitative, quantitative or descriptive. The process of mapping depends mainly of the risk model and of the available data.
- Existing flood event map or model outputs with exceedance probabilities are used as input to the hazard map. A new approach consists of the use of integrated 1D-2D model outputs.
- Vulnerability mapping is in its infancy. Development of methodologies to gather vulnerability data are of growing interest. The confidentiality and the privacy of the required data could limit the exercise. Use of participatory processes could be an alternative to the lack of qualitative data.
- Innovative approaches in flood risk mapping consist of the integration of the spatio-temporal dimension of flood event. They need the use of new Information and Communication Technology such as the SQL and ODBC (database management and query) or Intelligence artificial (social behaviour modelling).

10.3 Mapping methodology

The Risk to Life model developed in this project is based on a decision support tree and has a semi-qualitative approach. The qualitative outputs (Risk level) are assessed with the hazard and vulnerability values of a given area and different conditions. A general representation of the mapping methodology is shown in Figure 10.1. The GIS format used in this methodology is a vector format with polygon topology. The hazard and vulnerability maps are first created with existing data and are then combined through a "union" process, i.e. features of both layers are combined into one feature, while maintaining the original features and attributes. The resulting layer, or more exactly resulting database, is used as an input of the decision tree model to produce the risk map. The decision tree model has been developed in Visual Basic Application on the ARCGIS9.1® platform to represent the decision tree process to facilitate the processing of mapping.

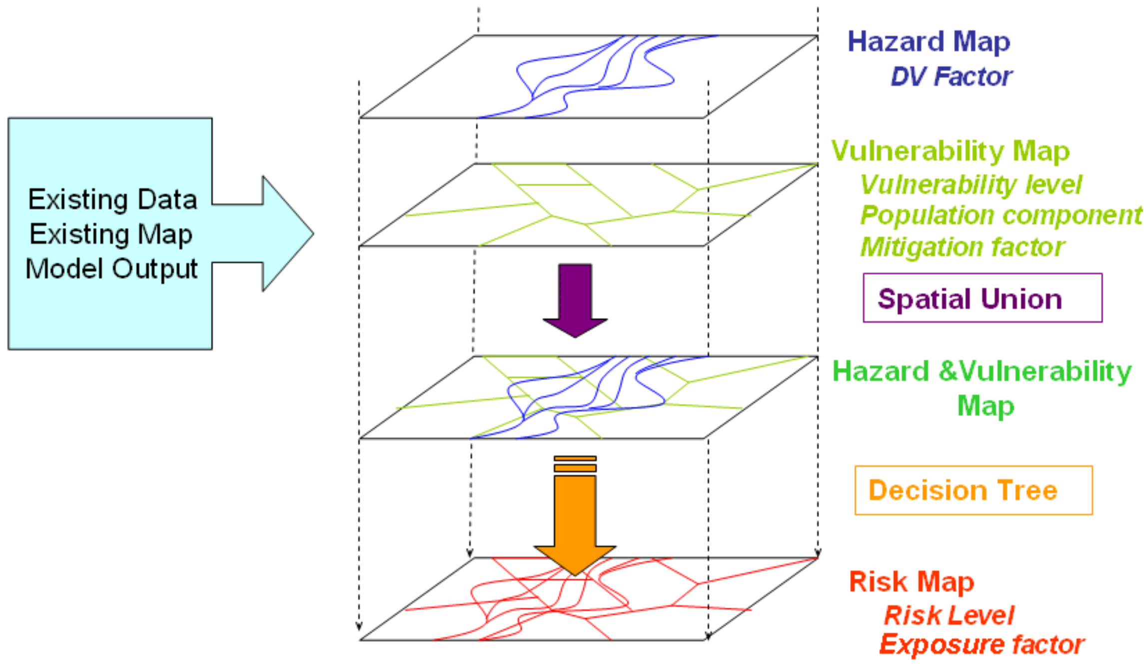


Figure 10.1: The mapping Process

In the next section the principle of the mapping process will be demonstrated through two cases studies, the Gard River (the town of Ales, France) and Thamesmead (UK). For the Gard River no data were available so the exercise consists of building a risk to life map based on existing information available on the internet. The Thamesmead data were received from research conducted by the Flood Risk Management Research Consortium (FRMRC), see Néelz and Pender, 2007.

10.3.1 The Hazard map

The Risk to Life model defines different outdoor hazards according to depth-velocity factor thresholds. To produce the hazard map it is necessary to define the extent of the flood and the depth-velocity value for a defined event (associated probability). It is unfortunately not easy to collect information on the velocity variable even with hydraulic models. It is usually easier to collect expert judgement on different portions of the flood area with potential depth-velocity value. Thus, in general, the hazard map would contain a "fixed" flooding area where the depth-velocity would change with different flood scenarios. If the hydraulic model gives the spatial and temporal dynamic of the depth and velocity value (usually in a raster format), it could be useful then to have "flexible" flooding areas. This means that for each time-series the hazard map has to be rebuilt according to the threshold values of the Risk to Life model and the output of the hydraulic model. Of course such a process will require more post-processing manipulation and is high time-consuming. One option would be to apply the risk to life model on a raster map and not on a vector map. Such issues represent high potential for further research and development.

Ales, the Gard river, France

Ales is one of the main towns in the Gard catchment. As outlined in Section X, the region experienced a dramatic flash flood in 2002 and seven major events have affected the *Languedoc-Roussillon* region during the last 100 years. The population in Ales is around 40 000 inhabitants. Around 590 ha (25 percent of the town area) is considered as potentially at risk. More than 18 000 people and also schools, camping sites, and playgrounds are also at according to the *DIREN* (2006).

No modelling outputs were available for this area. Thus the purpose here is to assess the potential use of the methodology regarding available information that could be found from secondary sources. The exercise was partly based on the Geointelligence method developed in natural resources management and economic evaluation of a related project. Geointelligence is knowledge extraction from networked databases of Earth images and digital maps (Gardner et al., 2003). The initial approach is to define the different spatial distribution of the flood hazard. For the Gard catchment two sources of information have been used (Figure 10.2):

> On the map server of the *DIREN*, http://www.languedoc-roussillon.ecologie.gouv.fr/loadPge.php?file=risques/inondation.file, different information on the flood risk area for the Gard catchment is available such as the different extents of flood events.
>
> On the DDE webserver: http://www.gard.equipement.gouv.fr/eau_environnement/AtlasZI/ZonesInondablesDuGard.asp, available maps show the potential flooding area for every town with an *IGN* map as the background.

The *DIREN* (2006) defines every channel bed depending on its probability to be flooded. The *mineur bed* or main channel is flooded in all the events. The *lit moyen* is flooded for a ten year event or less frequency. The *lit major and exceptionnel* is flooded for rarer events (here defined as a flood frequency of less than 20 years for *lit major* and 50 years for *lit exceptionnel*).

Once the potential flood area is defined, it is necessary to know the depth-velocity value for each event. As already mentioned, velocity and depth value are usually not available. Depth could be assessed from existing measures or from elevation maps like DTM with high accuracy. For a flood event, the mean or the maximum discharge (m^3/s) is mostly found for a river point. If it is not possible, as in this case study, to obtain values on velocity and depth, the only way to assess the depth-velocity value is to assume that the flow is uniform. The velocity and the depth are then considered as invariant along the river transect, so that the depth velocity factor equals the discharge divided by the width of the river transect.

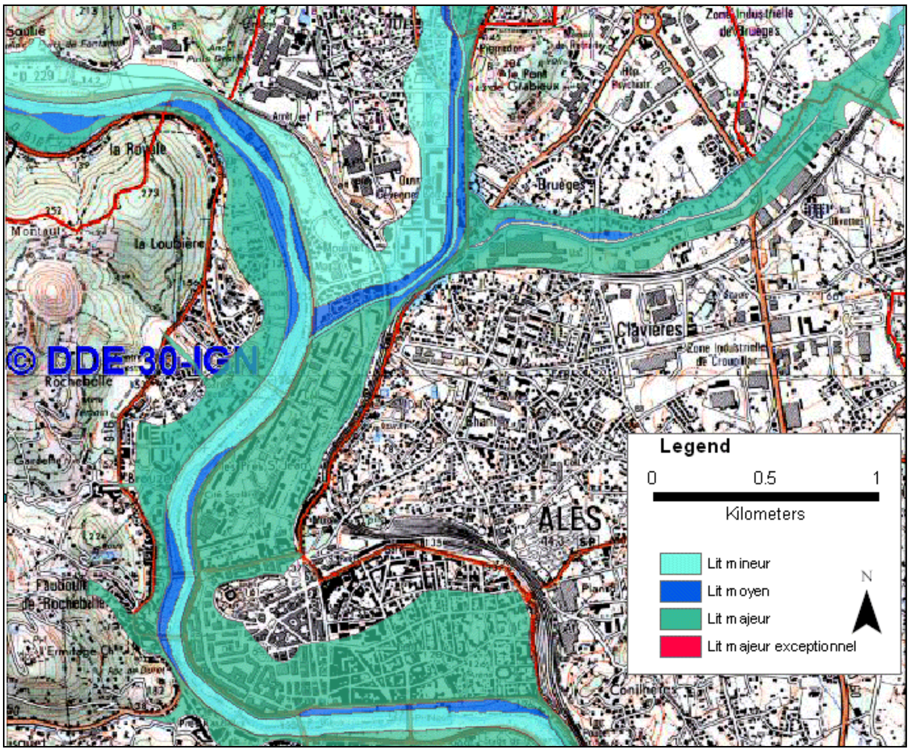


Figure 10.2: Resulting flood hazard area for the town of Ales

In France, the hydro bank (http://www.hydro.eaufrance.fr/) contains different information on French river stations. It provides syntheses of flood and hydrologic parameters as the maximal discharge observed and the estimated instant and mean discharge for different flood events. These values have been collected for the Gard river; 14 stations with maximal observed discharge values and 7 with estimated discharges. There is a strong correlation on this catchment between the drainage area (km²) and the instant discharges (m³/s). Table 10.1 shows the various relations found for each flood event.

Table 10.1: Relations between drainage area (km²) and instant discharges (m³/s) on the Gard river

Flood return period	a value Discharge = a * (catchment area)	Correlation factor
Two	0.98	0.978
Five	1.44	0.979
Ten	1.77	0.98
Twenty	2.03	0.98
Fifty	3.24	0.61

Given our assumption, the depth-velocity factor varies at the urban scale for two reasons. The first is the existence of different tributaries with different catchment areas. In our case study the catchment areas have been assessed from available DTM on Google Earth and on http://srtm.csi.cgiar.org/. The DTM has a 90 metre resolution, and elevation precision is one metre with a 15 m error. So the DTM could not be used to assess flood area and depth. The second reason is the change in river width. Thus different portions of the river have been selected on this criterion in order to represent potential changes on depth velocity values (Figure 10.3). All these results have to be approached with caution as no detailed studies of the site have been conducted. Thus the results have to be considered as a first approach to assess the hazard map.

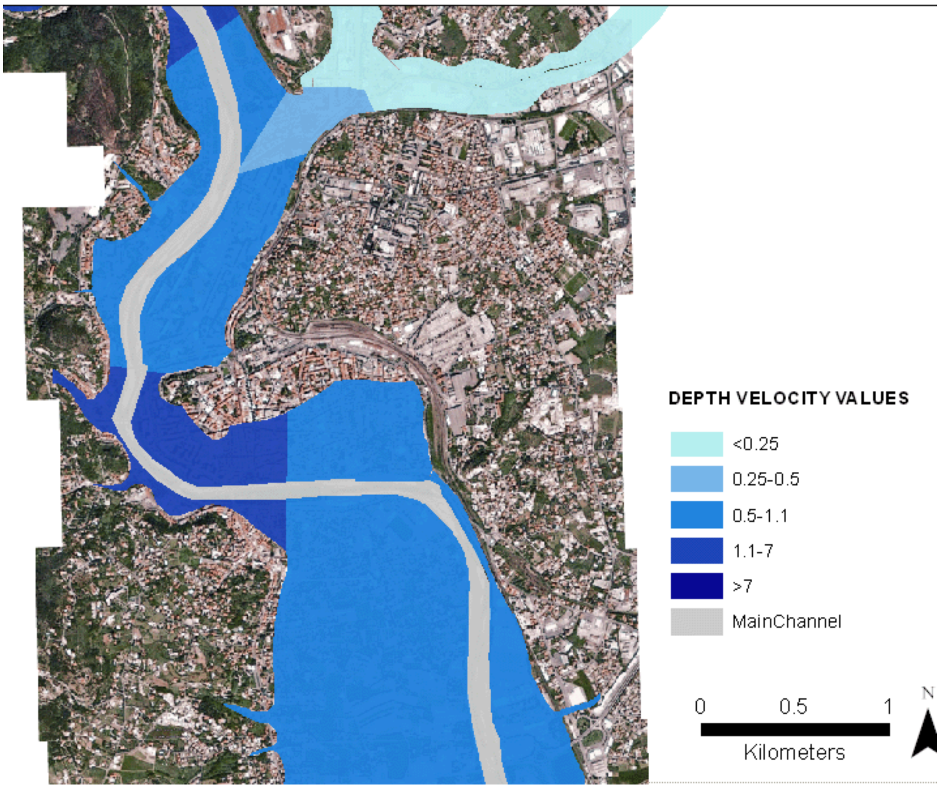


Figure 10.3: Estimated Depth-Velocity Factor for a twenty years event in Ales

Thamesmead - UK

Thamesmead is a five km² area of lowland along the banks of the Thames estuary just downstream from Thames Barrier. The area is below sea level and, without the presence of very high flood defences (protection against the 1:1,000 year flood), would be at risk from tidal flooding. The area was inundated during the North Sea Flood of 1953. At this time the area comprised only marshland, as the town was constructed later in the late 1960s (Gaume *et al*., 2007). No record of existing deaths or injuries from flooding exists.

A recent study, conducted by the school of the Built Environment (Heriot-Watt University – Edinburgh) for the Flood Risk Management Research Consortium (FRMRC) project, has considered the 2-D modelling of a hypothetical flood event affecting this flood plain based on the scenario of both a high tidal level and breach in flood defences (Néelz and Pender, 2007). The software used was TUFLOW, a computational engine that provides dynamically linked 2D and 1D solutions of the three-surface flow equation to simulate river flow and flood propagation (Néelz and Pender, 2007). The outputs of the model are the depth and the velocity at a given time and these are exported in a raster format. The hazard (depth * velocity) has first been estimated on a raster grid (Figure 10.4) and then been converted into polygon on the basis of the risk to life model thresholds values (Figure 10.5).

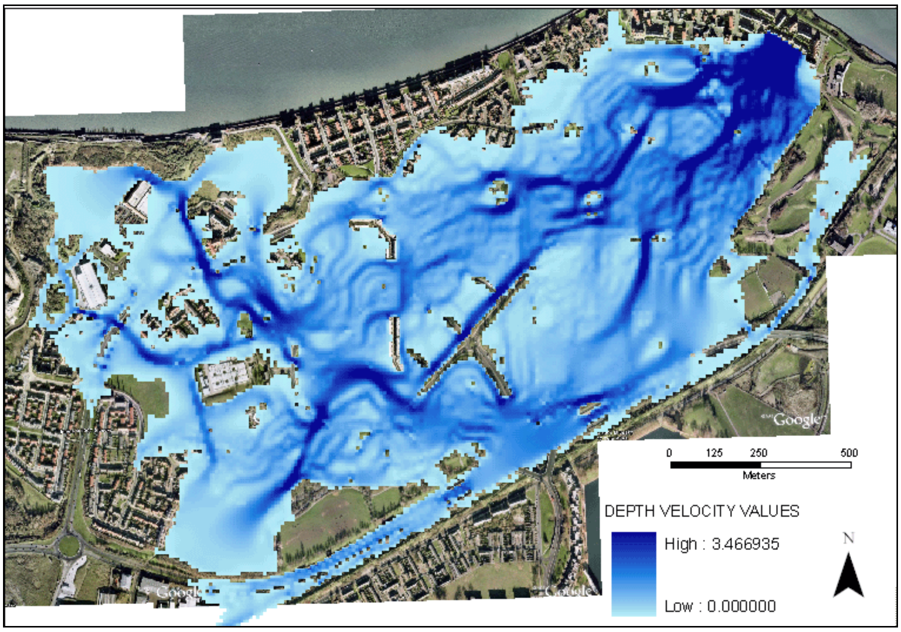


Figure 10.4: Output raster of the TUFLOW model – three hour after the defence break

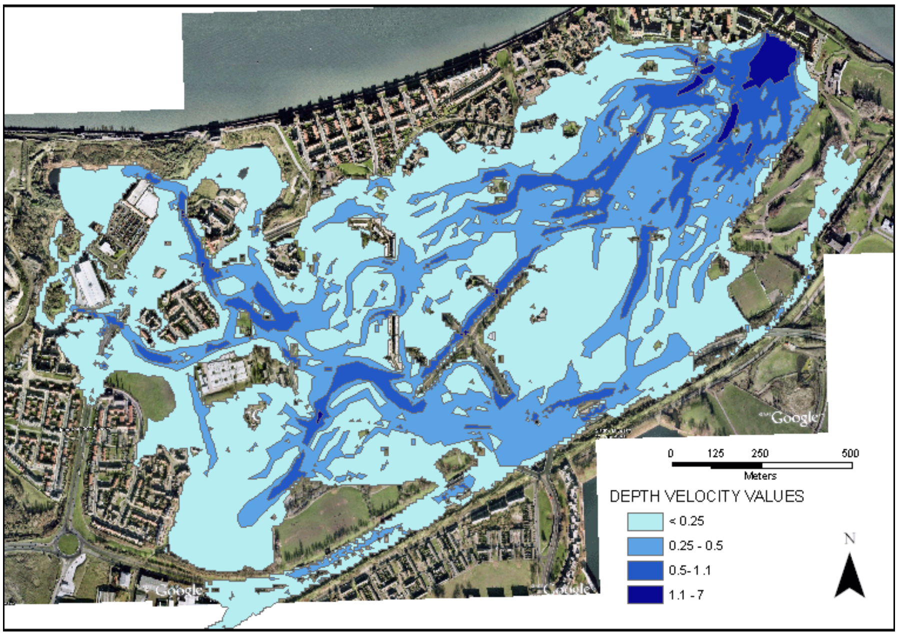


Figure 10.5: Estimated Depth-Velocity Factor for Thames Mead- Hypothetical scenario

10.3.2 The vulnerability map

The vulnerability map contains three levels of information: the vulnerability level, the population component and 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. For instance, an open field or a campsite would be highly vulnerable as there is no shelter on the site. However, to define the degree of vulnerability for certain types of land-use it is sometimes necessary to use expert knowledge on the type of buildings that could be found. Typically a rural residential area in the UK will probably be less vulnerable than a rural residential area in Poland due to the high quality of building construction. In the same way the vulnerability could change depending on the activities within an area e.g. the presence of schools, hospital or care homes.

Ales, the Gard river, France

In the case of Ales town the vulnerability map has first been defined from the Corine Land Cover data with the support of Google Earth and IGN (*Institut Geographique National*) map. It has been assumed that continuous urban fabric (town centre) has a low vulnerability, that discontinuous urban fabric, commercial units and industrial units have a medium vulnerability and that open fields have a high vulnerability for risk to life. Specific spots like schools, camp sites, hospitals, old people homes and clinics have been pinpointed on the map. These points and their surroundings have been classified as highly vulnerable whatever their first classification (low or medium). The resulting vulnerability map is illustrated in Figure 10.6.

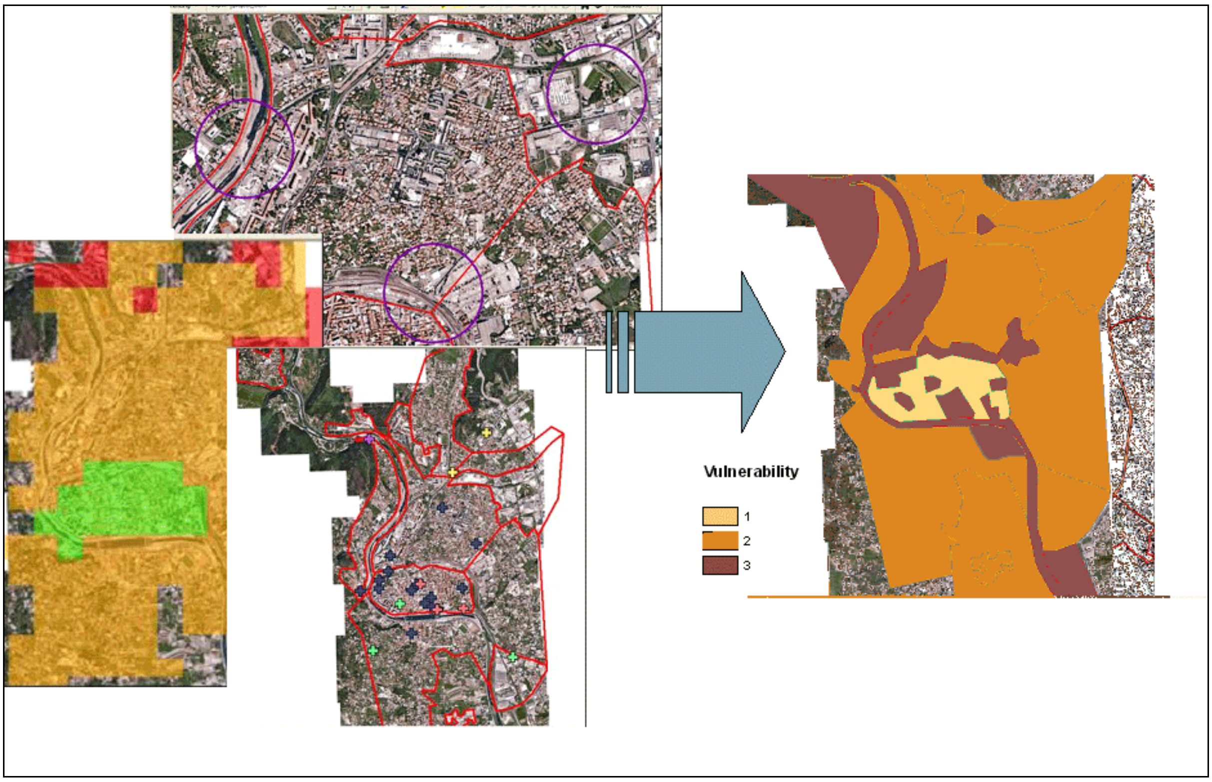


Figure 10.6: Integration of different sources of information (CLC, Google earth, points on the left) and creation of the vulnerability map (right)

The population component has been estimated from the population density issued from the French National Census data (*INSEE* www.insee.fr). Detailed data at the scale of suburban area are also available (Figure 10.7) and give details of the population according to age. On this basis two types of population have been defined: vulnerable people (less than 20 years and more than 75 years of age) and the total population. For the moment the real population present in-situ according to the type of activity and the time period (school, campsite) has not been considered, except on the river bed where the population is null. We have also not considered people outside or inside poor quality buildings. No mitigation factors have been tested, i.e. we assume that there is no warning and no evacuation. Such scenarios should be built at the town scale through participatory processes in further studies.

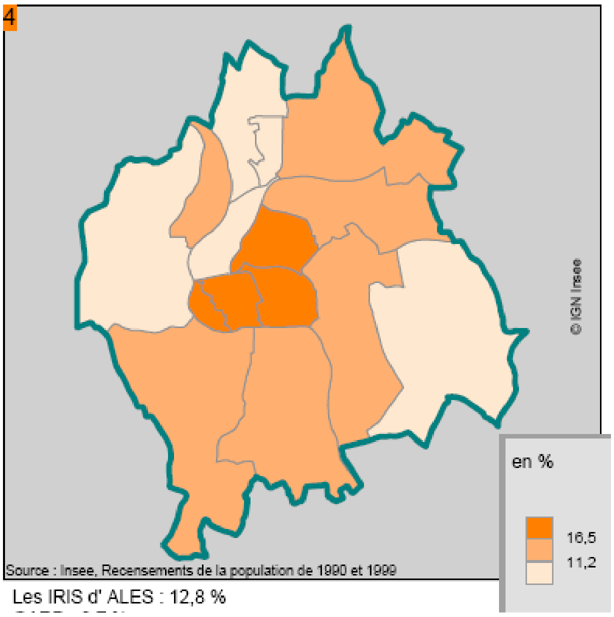


Figure 10.7: Percentage of population aged more than 75 year-old in 1999 (INSEE)

Thamesmead - UK

The vulnerability map (Figure 10.7) has been defined using the Environment Agency's National Properties Dataset with the support of Google Earth. The National Properties Dataset provides information on every building of England and Wales by postcode and type of activities in a GIS format. Data on population (UK 2001 census) have been collected at Output area level (Figure 10.8) from the Neighbourhood National statistics website (http://neighbourhood.statistics.gov.uk/). Vulnerable population has been classified as population under 15 and over 75 years of age. For every house in the database classified as residential, potential numbers of vulnerable people and of total population have been spatially defined and then aggregated with the vulnerable area. For the moment it has been considered in the model that all the population are in their residential area. This means that no one is in school, in surgery, in an open field, or in a commercial unit during the event. As for the French case study, we have also not considered whether people are outside or inside properties and we have not yet included mitigation factors.

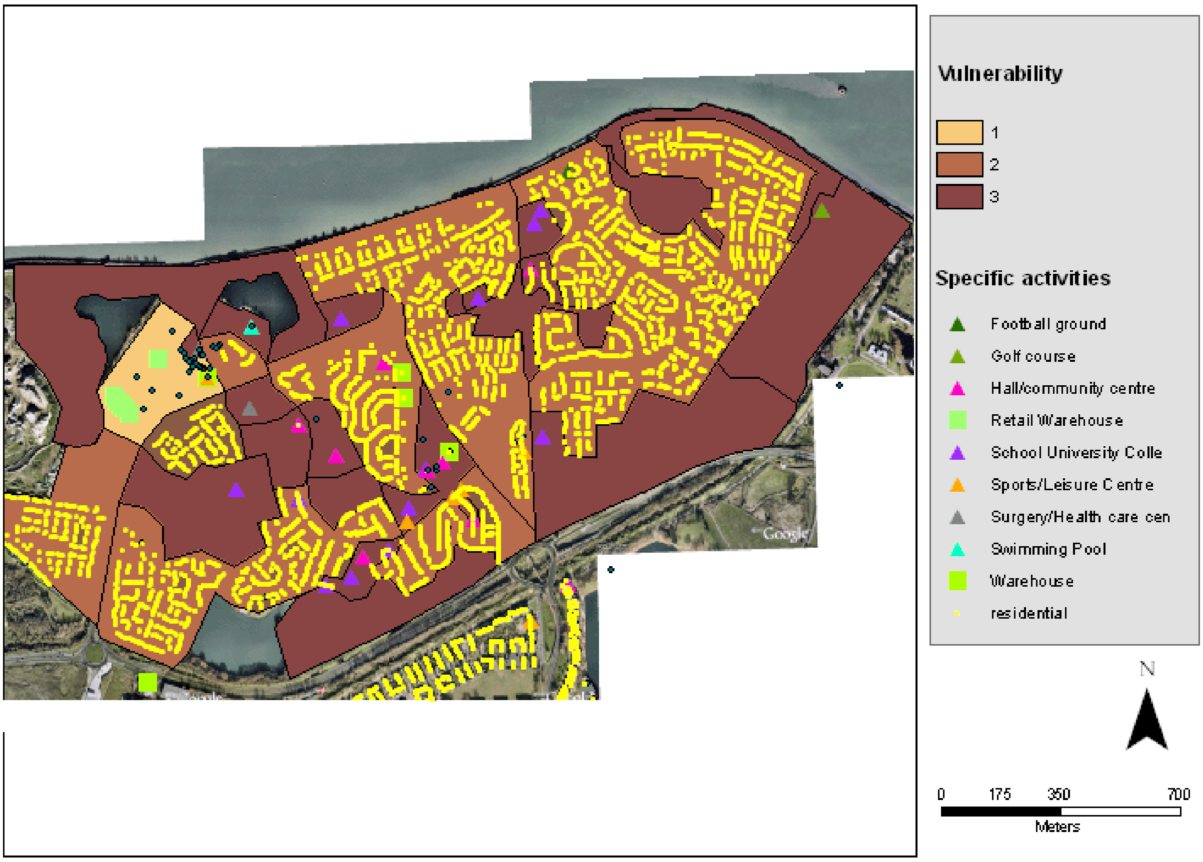


Figure 10.7: Vulnerability map – Thamesmead

Figure 10.8: Output Area cover example (delimited by white contour)

10.3.3 The Decision Tree model

Once the required data are collected and added to a dedicated database, a simple model (Figure 10.9) is used to define, for each area, the risk level and the exposure factor (Figure 10.10). The threshold value of the depth-velocity factor could be changed in the tool to take into account local specificities. The exposure factor is assessed according to the population present in the area and an impact factor. The impact factor value changes with the risk level and multiplies the population present in the area.

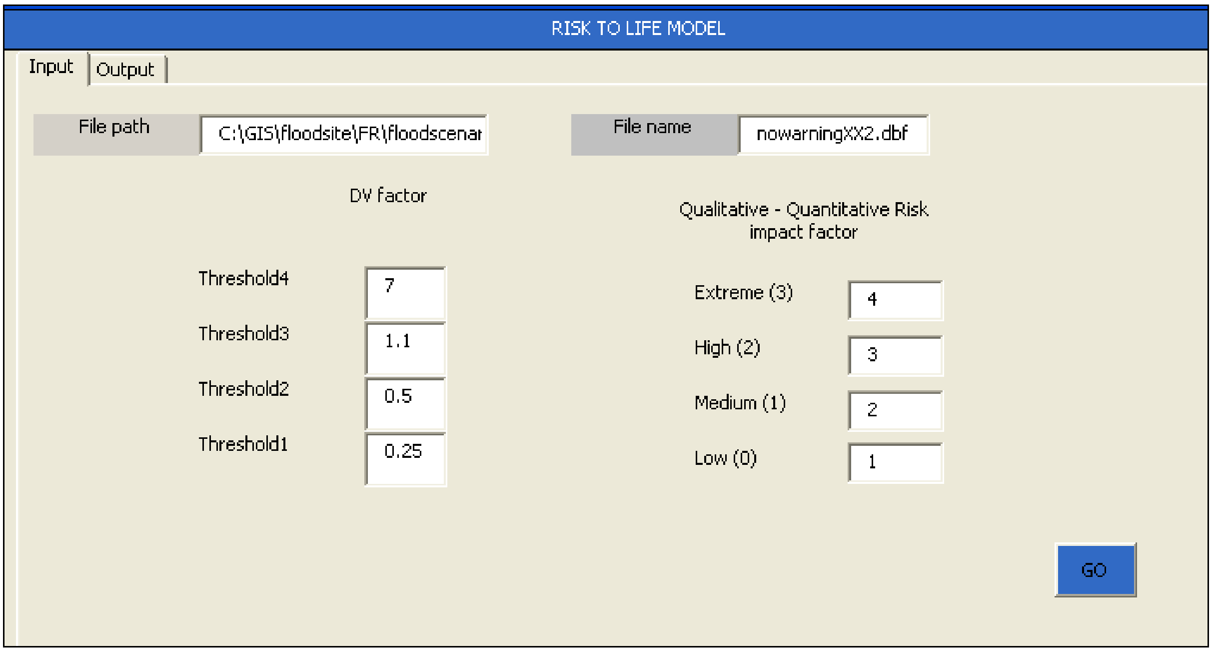


Figure 10.9: Input interface – the risk to life model

10.3.4 Expected results

The output interface of the risk to life model (Figure 10.11) summarizes the results of the model. The total number of features and the total area is given for each class (Extreme, High, Medium and Low). The “Risk to Life without mitigation” columns correspond to the risk to life categories without mitigation column of the model. The “Risk to Life with actions” corresponds to the risk to life categories with mitigating actions. Thus it allows an overview of the warning and evacuation scenarios. The “exposure factor” column gives the potential number of people exposed to the risk multiplied by the risk factor associated with a risk class. It gives a range of values to assess the implications for risk to life but does not give an expected number of injuries or deaths. These results can also be mapped as shown for the two case studies below.

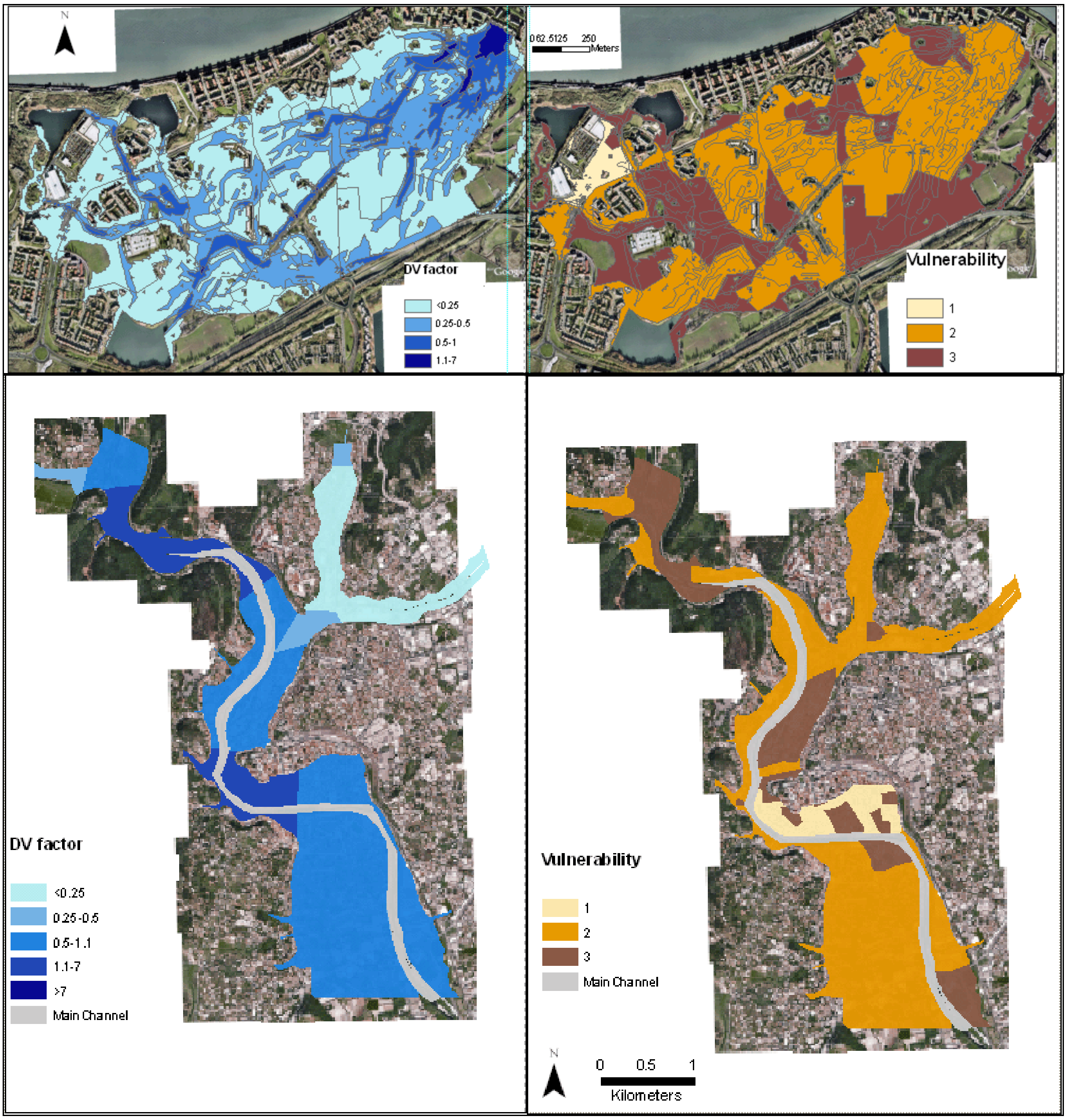


Figure 10.10: Resulting maps obtained by spatial union and used as an input in the risk to life model for both case studies. Depth Velocity factor and Vulnerability are represented.

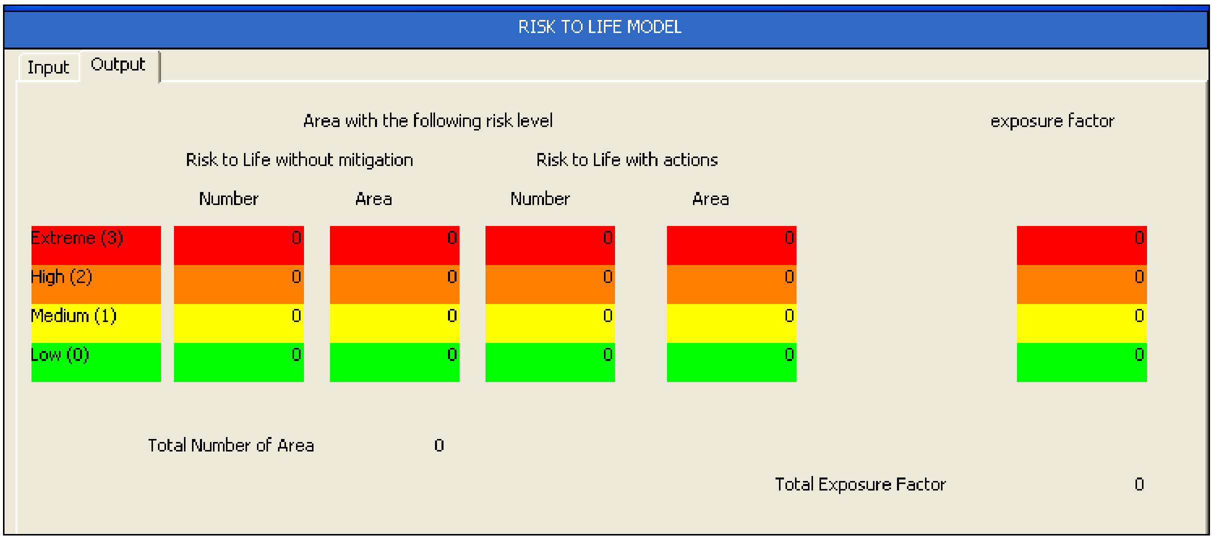


Figure 10.11: Output Interface – the risk to life model

Ales, the Gard river, France

The model has been tested in the case of Ales for a twenty year flood event with no warning and evacuation process. Figure 10.12 shows the resulting output interface. As no warnings are tested, the comparative columns present the same results. The risk is generally considered as high with a total surface of 456 ha and an exposure factor of 42 950. The area at medium risk is relatively small at 93 ha but presents a relatively high risk factor.

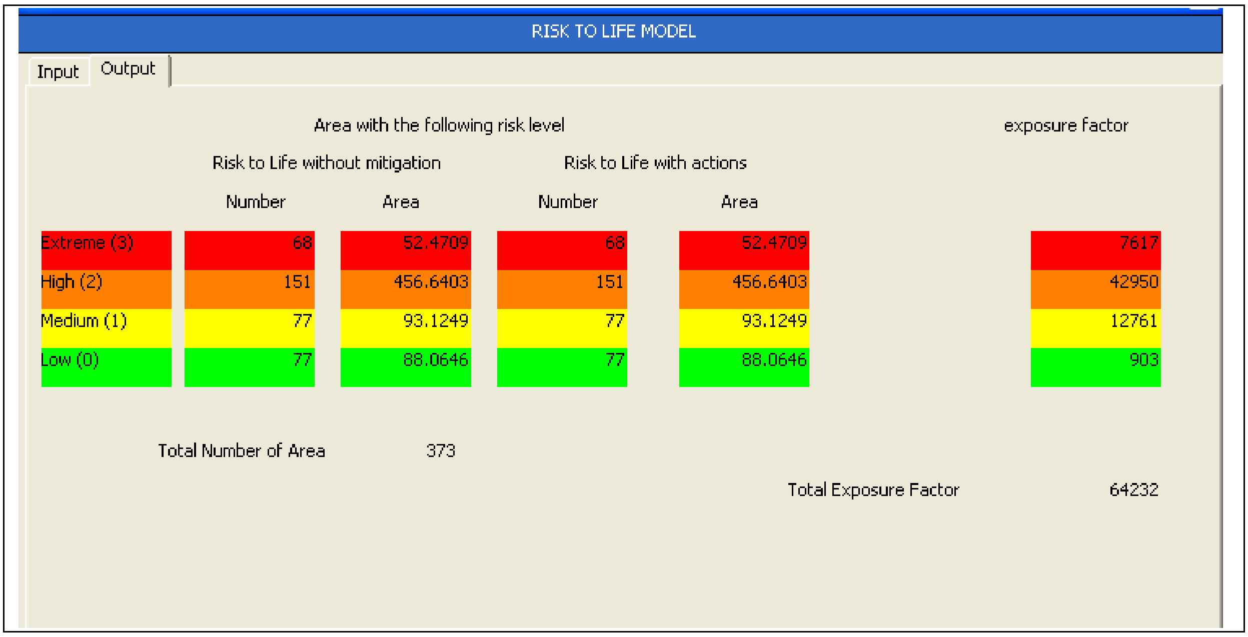


Figure 10.12: Results in the Output Interface - French case study

The three following Figures (10.13 to 10.15) show the different maps that could be built with the model results. The high risk areas are dominant for the entire town. An extreme risk area can be seen in the town centre. This could be explained by the presence of a highly vulnerable area and by the narrowing of the river. The risk to life exposure factor is partly dependant on the size of the designated area. Thus the town centre appears to be less exposed than the surrounding area. This type of map could be useful to assess evacuation scenarios in designated areas where the population number is well-defined. If this is not the case then such maps need to be used with caution. The main problem is that the exposure factor equals the population multiplied by the risk factor. The risk factor is at the moment defined on a very small scale (1 to 4). If the sizes of the areas are very different (for instance one area is 20 times smaller than the others) then the difference in population masks the impact on the risk factor. To correct this, it is better to estimate the risk to life exposure factor per ha as shown on Figure 10.15, i.e. to give the potential density of people exposed to the risk multiplied by the risk factor associated with a risk class.

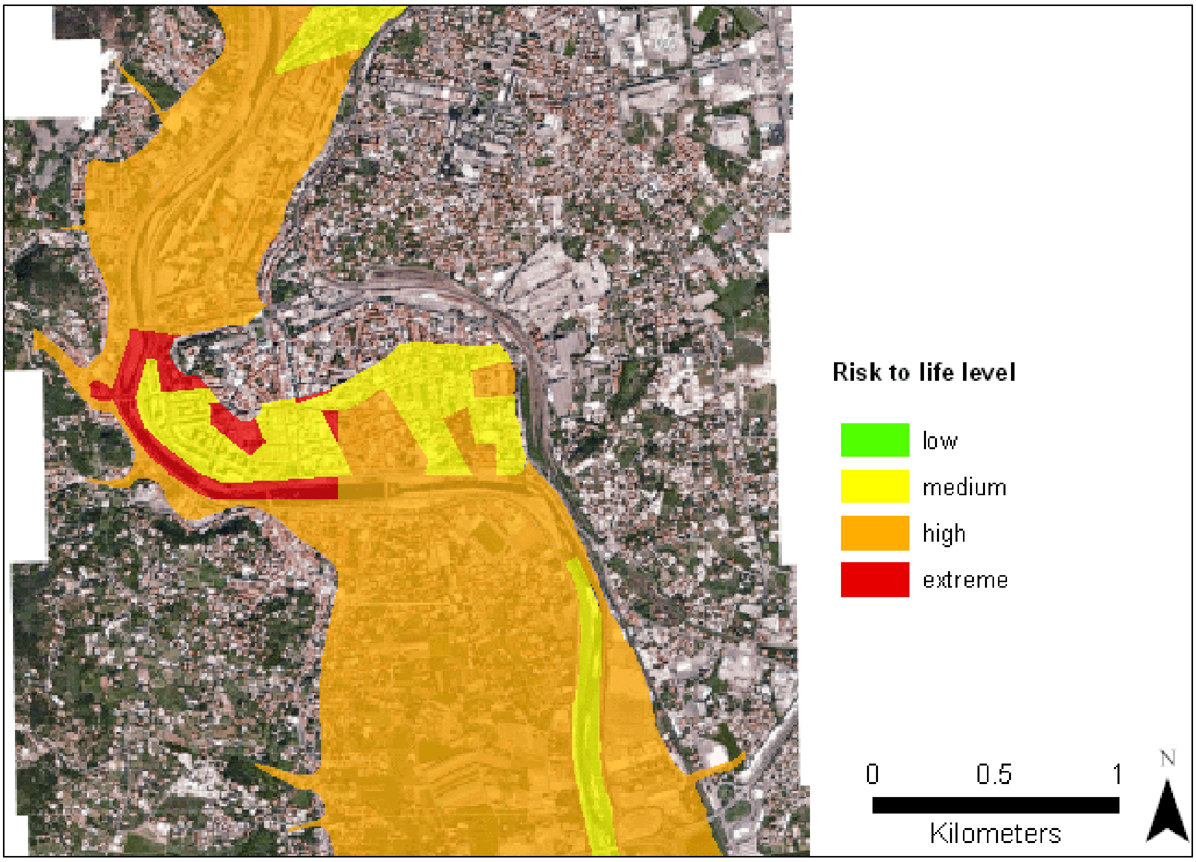


Figure 10.13: Risk to life level – Ales Town

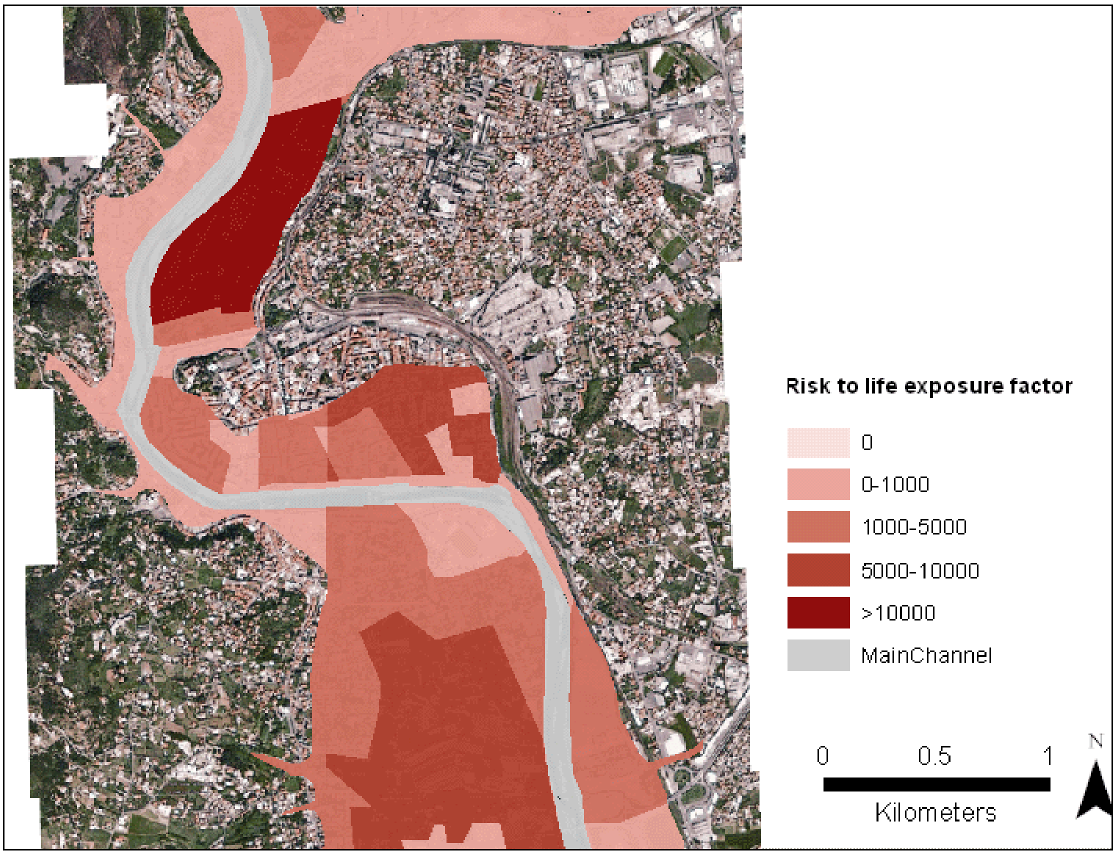


Figure 10.14: Estimated risk to life exposure factor- Ales town

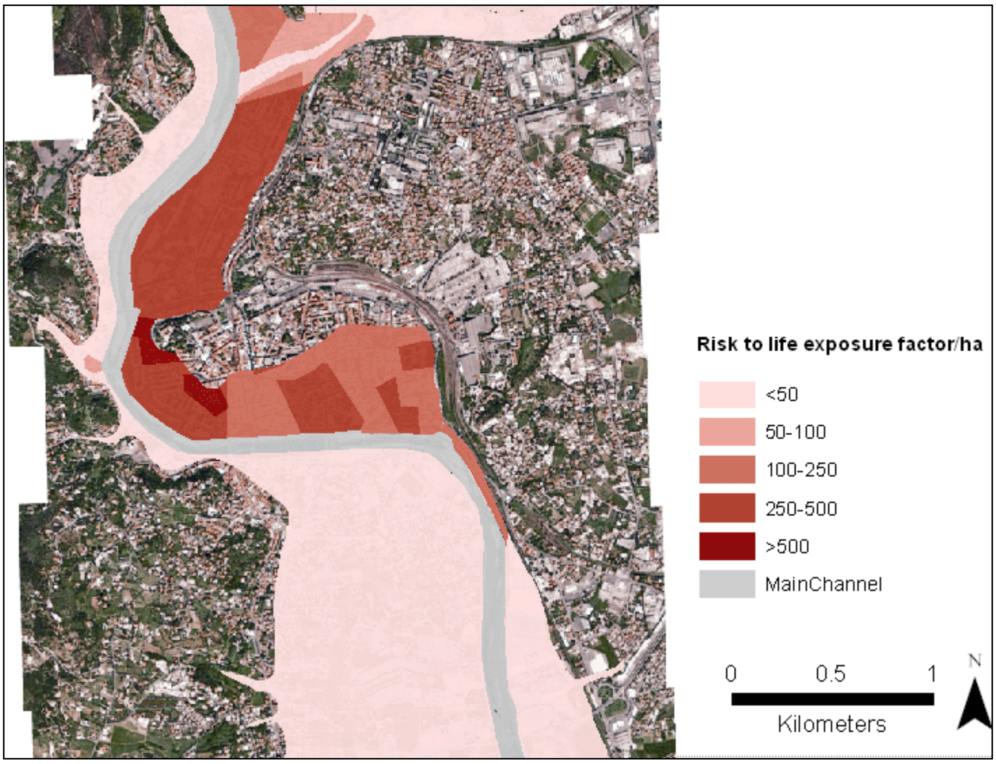
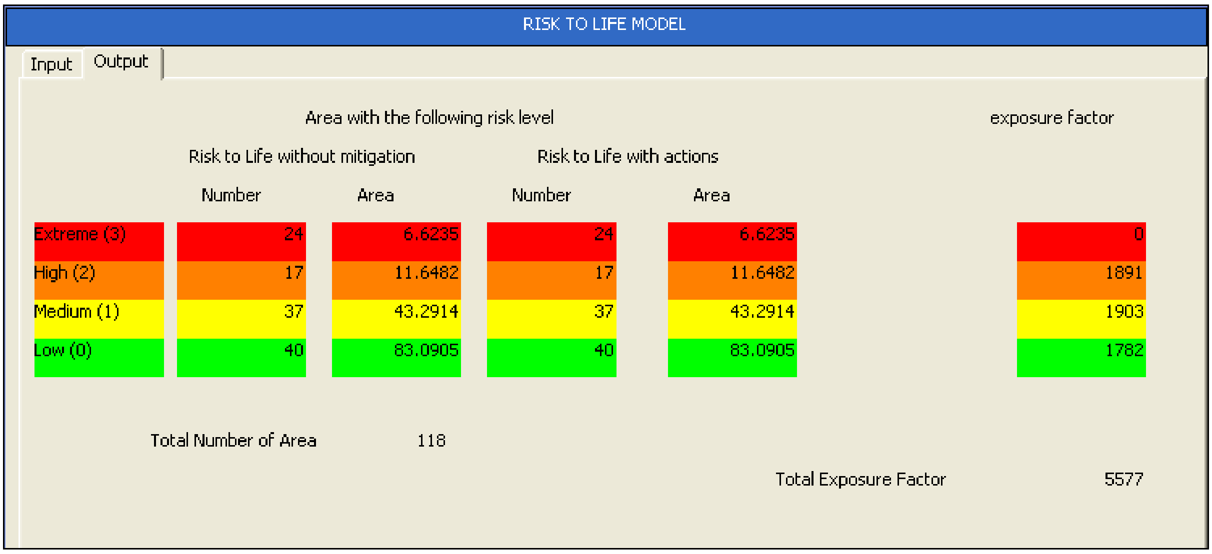


Figure 10.15: Estimated risk to life exposure factor per Ha - Ales town

Thamesmead – UK

The results for the Thamesmead area are very different from those for Ales the French case study. We are here in the case of a breach in the flood defence of a flood plain. The size of the risk areas decreases with the risk value (Figure 10.16). The water spreads on the lowland with no extremely high depth velocity values (less than 3.5 m²/s). The resulting extreme class is thus limited to high vulnerability area (see model). As the population is limited to residential area (medium vulnerability), it explained why the exposure factor is null for this class. This also explains why at the dam breach the risk to life is mainly high and not extreme (Figure 10.17). The map of exposure factors (Figures 10.18 and 10.19) corrects this impression by stressing that main population affected is the one closest to the defence break. The BC hydro Life Safety model has been applied in FLOOD*site* Task 17 on the same case study (Gaume *et al.*, 2007). Unfortunately results cannot be compared as different flood scenarios have been applied. Such comparison could be investigated in further collaboration.


RISK TO LIFE MODEL

Input | Output

	Area with the following risk level				exposure factor
	Risk to Life without mitigation		Risk to Life with actions		
	Number	Area	Number	Area	
Extreme (3)	24	6.6235	24	6.6235	0
High (2)	17	11.6482	17	11.6482	1891
Medium (1)	37	43.2914	37	43.2914	1903
Low (0)	40	83.0905	40	83.0905	1782

Total Number of Area 118

Total Exposure Factor 5577

Figure 10.16: Results in the Output Interface - UK case study

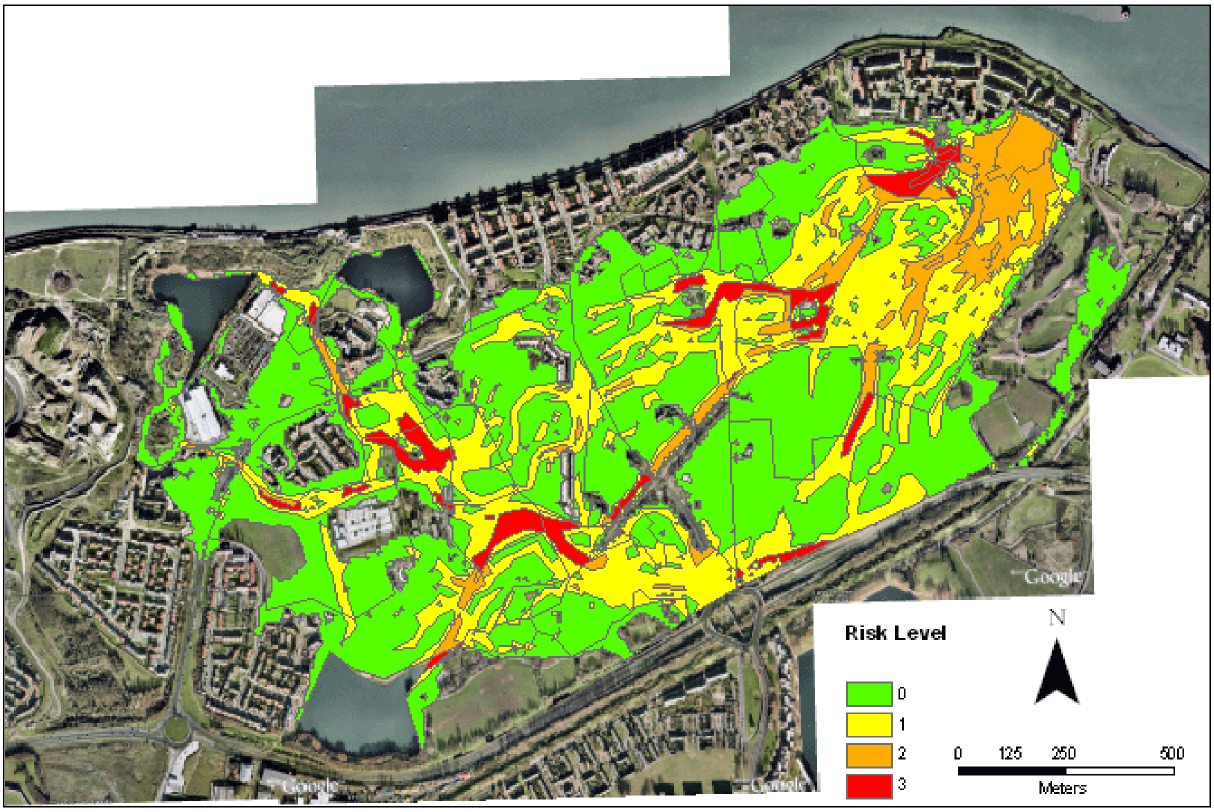


Figure 10.17: Risk to life level – Thames Mead

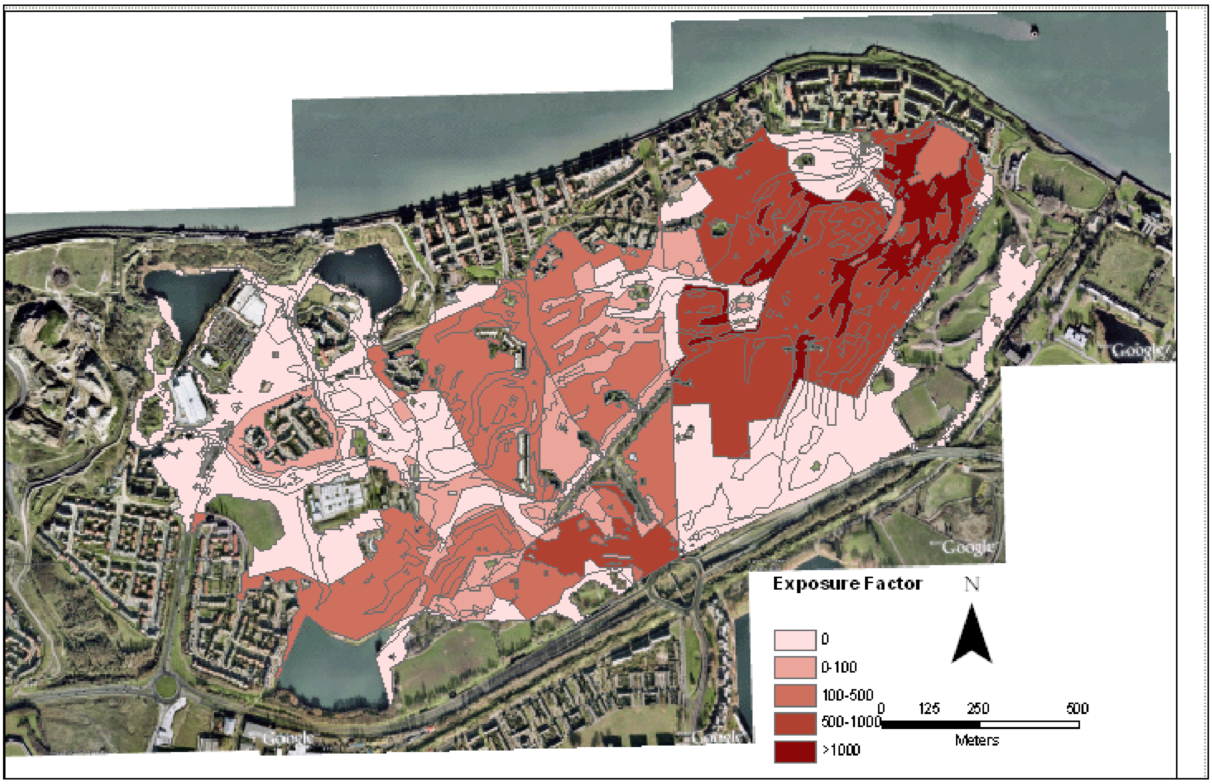


Figure 10.18: Estimated risk to life exposure factor- Thames Mead

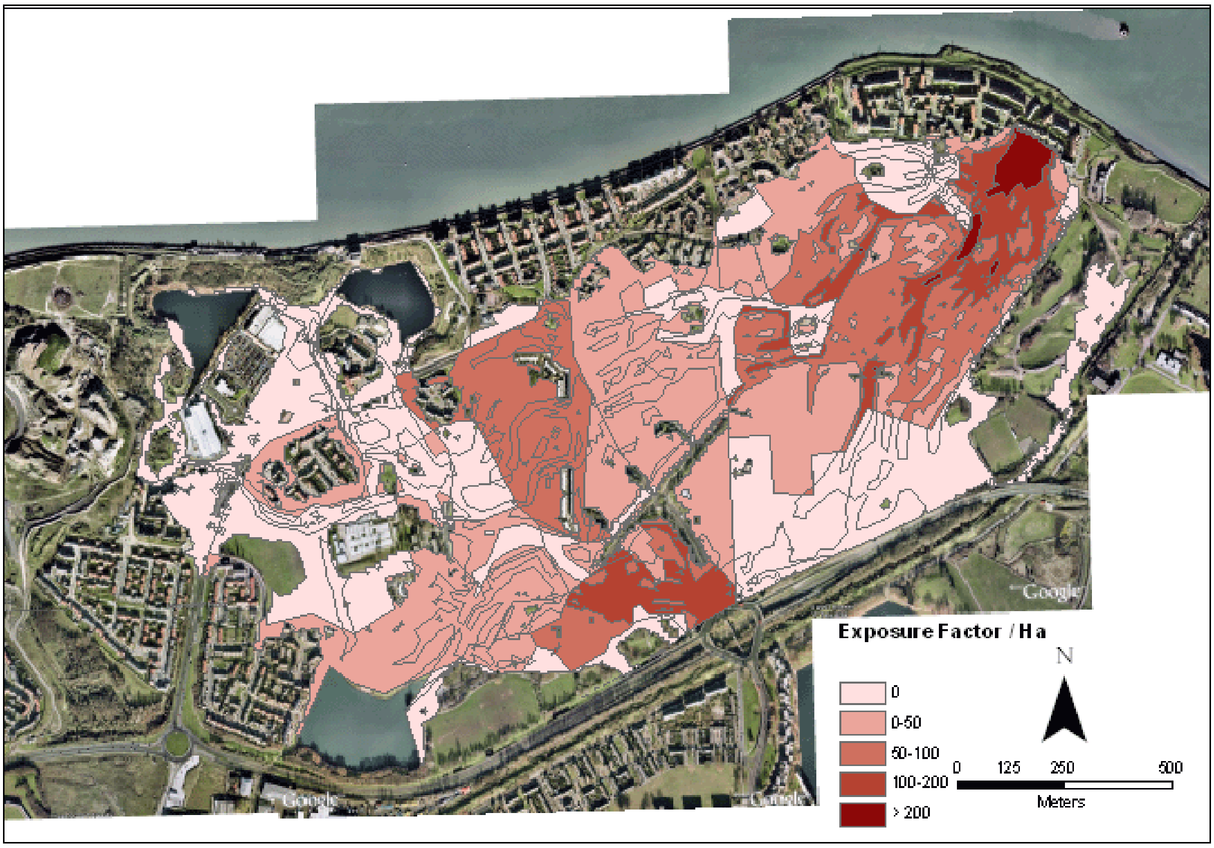


Figure 10.19: Estimated risk to life exposure factor per Ha – Thames Mead

10.4 Evaluation and application within a European flood management framework

In this section we attempt to show how to apply the flood Risk to Life model using a GIS. The mapping process is based on post processing of collected database. Four components need to be collected and mapped:

- the hazard
- population vulnerability
- population size
- mitigation planning

The hazard map represents the spatial extent of the flood plus depth/velocity values. Depending on the available resources, the hazard map could be more or less accurate. The best approach is to use output from 1D/2D models. To build the vulnerability map we propose an easy approach based on a three levels classification of vulnerability depending on the land use and type of buildings. The information required is easy to access through internet information, from local maps or from local knowledge. The establishment of the population map is probably the most difficult exercise in the mapping process. We could consider two levels. The first level, shown in this report, consists of building two classic population maps based on census data: one for the vulnerable people, one for the total population. The second level, only mentioned in this report, consists of building scenarios on how the population lives and works on the site. The exercise requires establishing where people are likely to be (e.g. outside, inside properties, at home, at work, at school) at specific times of the year, week or day and how this will affect the risk to life. The mitigation planning map shows existing or potential warning and evacuation system. The system could be applied for all the area or for specific sites. One of the major issues of the model is indeed to compare the effect of such action plan.

The final maps (Figure 10.10) computed from the previous maps are used as an input to the risk to life model. A tool has been specifically developed under ArcGIS in Visual Basic Application to estimate the risk to life value. It could be used easily by other users on specific case studies. Most of the potential of the model has not yet been tested e.g. comparisons of different events, of population scenarios and of warning and evacuation scenarios. Moreover, the result of the model has not been calibrated with real events.

There is thus still much further research that can be undertaken: the model requires further testing and calibration and refinements in order for it to be effectively operationalised. We also strongly believe that participatory processes at case study sites would be highly relevant to identify vulnerability areas, to build scenarios and to ground-truth the model.

11. Conclusions and recommendations for further research

11.1 Summary of research and results

The overall objective of Task 10 of the FLOOD*site* project is to focus research efforts on innovative methods to understand, model and evaluate flood damages. One aspect of this damage relates to risk to human life and serious injury resulting from flooding. In order to reduce the risk to life 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 as follows:

- to further develop a model, or models, that will 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, 2005) and assessed the applicability of this model for flood events in Continental Europe, which tend to be more severe. 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. A number of problems were identified with the current model when applied to the flood data from Continental Europe. Firstly, despite the model yielding reasonable estimates for UK case studies, the Hazard Rating component of the formula was not designed for the major rivers and mountainous catchments of Continental Europe and the extreme values for HR generated by the European data resulted in dramatic over-predictions of injuries and fatalities. The model was found to contain two structural weaknesses: a Hazard Rating of greater than 50 was seen to result in more fatalities being predicted than injuries, and when HR and PV values were high the model became unstable and tended to predict more injured people than were in the hazard zones. Moreover, research into the factors surrounding European fatalities also highlighted that more account needs to be taken of institutional arrangements and mitigating factors such as evacuation and rescue operations in the Area Vulnerability component of the model. In addition, the model was hugely sensitive to People Vulnerability, which is arguably of less importance in the wider European flooding context than it is in the UK.

Thus a new semi-quantitative ‘threshold’ model which combines hazard and exposure thresholds and mitigating factors has been developed to assess risk to life from 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.

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.

11.2 Remaining issues

A number of problems remain in refining the model further. Firstly, the results generated from the application of the new approach are, similar to other models of this type, hugely sensitive to the data input into the model and the different values attributed to the model components. This factor, along with general limitations in the availability of data, have highlighted the need for the establishment of reliable, systematic and consistent methods for collecting data following flood events across Europe, as well as for the need to make available such data that is collected. A key constraint relates to who is responsible for collecting such data, which at present varies from agencies at local, regional and national levels. Therefore it is suggested that protocols are needed to address this 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.

Several questions can also be raised at this point about the purpose of modelling risk to life. For instance, is it aimed at modelling a worse case scenario? It is unlikely that it will ever be possible to estimate accurately the number of deaths from a flood event. Therefore, should the modelling simply be used as a guide to the identification of those areas which are most likely to suffer fatalities from flooding? It is also possible to question the feasibility of trying to apply one model to assess the risk to life for the whole of Europe due to the large differences in types of flood hazard, area and people vulnerability and institutional arrangements.

11.3 Recommendations for further research

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.

- 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.

- 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 vulnerable areas, to build scenarios and to ground-truth the model.

12. References

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13. Appendices

Appendix A: Global flood event statistics

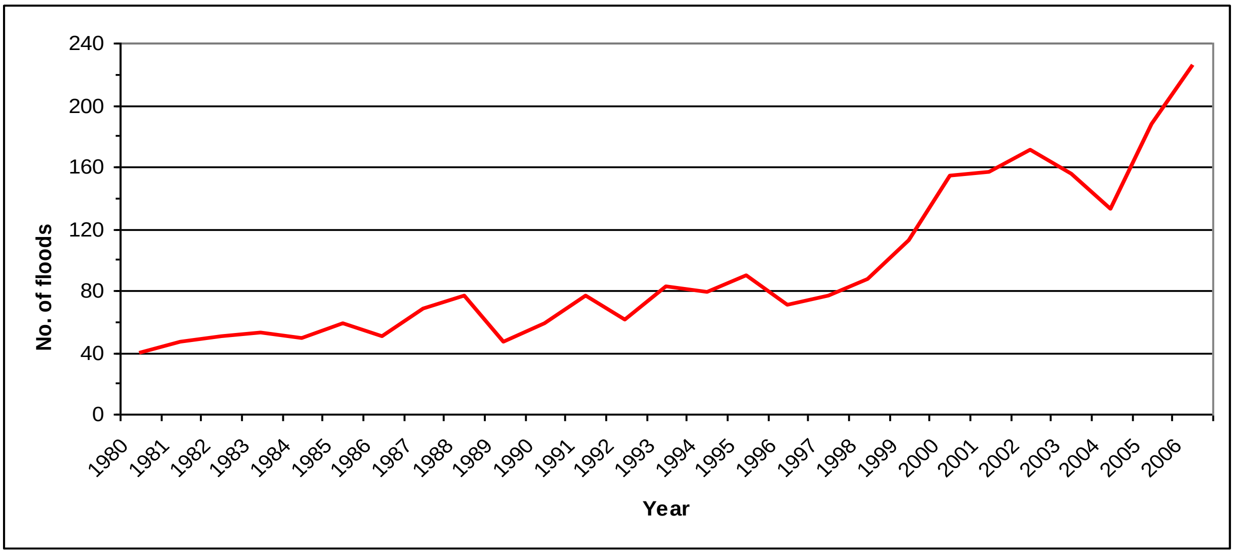

Figure A1: Annual number of reported flood disasters20 1980-2006
Source: EM-DAT the OFDA/CRED International Disaster Database, www.em-dat.net (Accessed: 22/01/07)

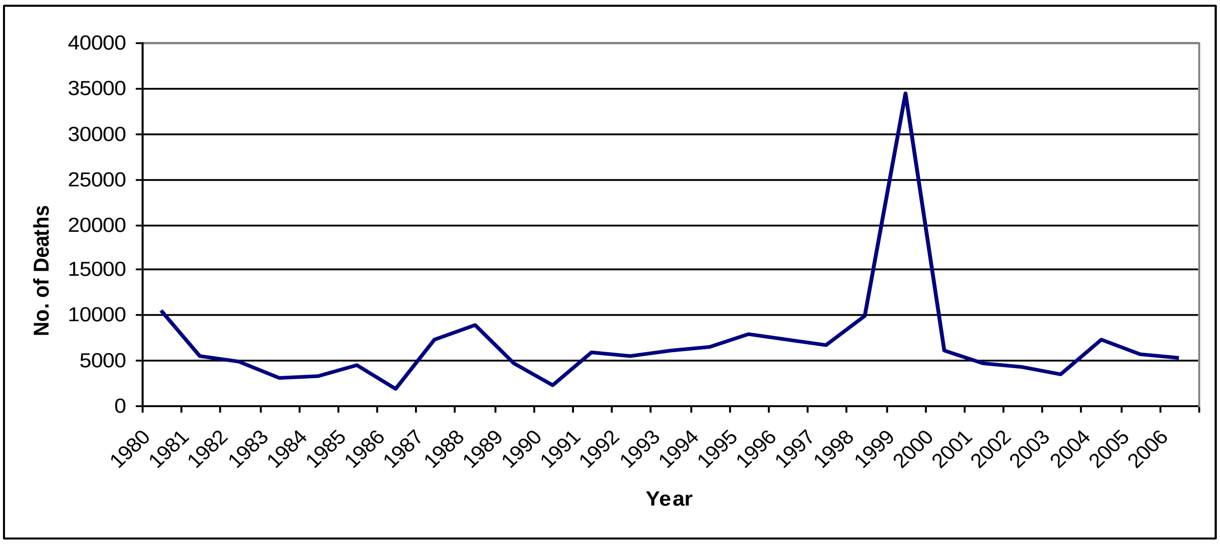

Figure A2: Annual number of reported deaths caused by flood disasters[1] 1980-2006
Source: EM-DAT the OFDA/CRED International Disaster Database, www.em-dat.net (Accessed: 22/01/07)

20 In order for an event to be recorded into the database, at least one of the following criteria must be fulfilled: 10 or more people killed, 100 or more people affected/injured/homeless, significant disaster, e.g. 'worst disaster in the decade', significant damage, e.g. 'most costly disaster'. Source: www.em-dat.net

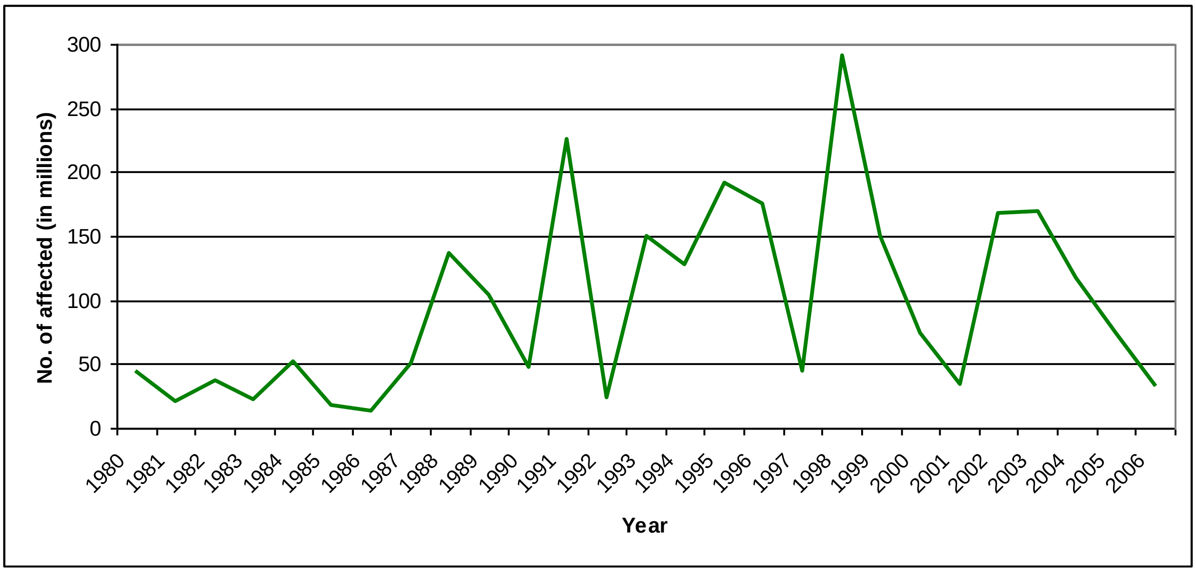

Figure A3: Annual reported number of people affected (in millions) by flood disasters[21] *1980-2006*

Source: EM-DAT the OFDA/CRED International Disaster Database, www.em-dat.net (Accessed: 22/01/07)

21 In order for an event to be recorded into the database, at least one of the following criteria must be fulfilled: 10 or more people killed, 100 or more people affected/injured/homeless, significant disaster, e.g. 'worst disaster in the decade', significant damage, e.g. 'most costly disaster'. Source: www.em-dat.net

Appendix B: Data collection template

Characteristics	Data requirement variables	Explanation
Area(s) characteristics[22] The affected area needs to be defined *by you* but should be a discrete area e.g. a small town or part of a town, a village etc. See note below.	Type of land use/ spatial development	E.g. majority is rural, urban, industrial or mixed use
	Flood warnings systems	Please state if warning systems are in place and, if so, whether systems are:- Good (where majority of people at risk received warning with adequate lead time) Fair (warning received by some of the population with adequate lead time) None (no warnings received) Information on warning *lead time* is also useful
	Type of buildings	E.g. multi-storey apartments, single storey houses, multi-storey houses, commercial/ industrial properties, mobile homes, campsites, schools. Could give approximate % of each type or what type majority are.
	Rate of rise/speed of onset	Low risk: onset very gradual over many hours Medium risk: onset is gradual , one hour or so High risk: rapid onset in minutes
	Building collapse	Number or (preferably) % of buildings in area collapsed or destroyed
	Evacuation	(Linked to flood warnings) Please state if people evacuated or not. If evacuated please state how many or % of people evacuated, also when evacuated, and duration
Flood characteristics	Details of flood	Date, location/name of area(s) affected.
	Depth	In metres
	Velocity	In metres per second
	Debris content	Size and type reported e.g. trees, rocks, cars
	Time of Flood	Can be approximate e.g. night-time, morning, afternoon, evening. Information on if weekday, weekend or holiday period also useful.
	Duration	Minutes, hours, days or weeks
People characteristics	Number of people affected in the area(s)/zones	Area(s) to be defined by you, see above
	Number of deaths	+ data on cause of death needed where available
	Number of seriously injured	+ data on cause/type of serious injuries needed where available
	Age 75+	% population in area aged 75 or over
	Health status	% population in area with long-term illness/disability
	Population with language constraints	% ethnic minorities, tourists, foreign workers
	Awareness of flood risk	E.g. % recent migrants and/or % second home owners, % tourists

[22] For some flood events the area characteristics may vary in terms of levels of hazard for different parts of the flood hazard area, for example for depth of flood or rate of rise. Where this is the case, it would be useful to have all the data disaggregated for the different flood 'zones'. Data for different variables may also vary according to the zone of flooding e.g. for flood warnings, type of buildings etc.

Appendix C: Full model output for UK data

		Flood Characteristics				Area Characteristics				People Vulnerability			**Predicted Injuries**	**Predicted Deaths**	**Actual Deaths**
Hazard Zone	N (Z)	depth	velocity	DF	**HR**	Speed of onset	Nature of area	Flood warning	**AV**	% of long term ill	% of very old	**PV**			
Gowdall	250	1	0.5	0	1.0	1	2	2	5	18%	7%	25%	13	0.25	0
Norwich 1	500	1.5	1	0	2.3	1	2	3	6		25%	25%	34	1.52	
Norwich 2	2,000	1	0.2	0	0.7	1	2	3	6		25%	25%	42	0.59	4
Lynmouth 1	100	3	4	1	14.5	3	2	3	8		26%	26%	60	17.36	
Lynmouth 2	100	2	3	1	8.0	3	2	3	8		26%	26%	33	5.28	
Lynmouth 3	200	1	2	0.5	3.0	3	2	3	8		26%	26%	25	1.49	34
Carlisle A	640	1.5	0.5	0	1.5	1	2	1	4	5%	2%	7%	5	0.16	
Carlisle B	420	1	0.5	0	1.0	1	2	2	5	20%	8%	28%	12	0.24	
Carlisle C	135	1.5	0.5	0	1.5	1	2	1	4	22%	7%	29%	5	0.14	
Carlisle D	888	1.5	0.5	0	1.5	1	2	2	5	20%	7%	27%	36	1.07	
Carlisle E	1,530	0.5	0.5	0	0.5	1	2	2	5	20%	7%	27%	21	0.21	3

Appendix D: Full model output for European data

			Flood Characteristics				**Area Characteristics**				**People Vulnerability**			**Predicted Injuries**	**Predicted Deaths**	**Actual Deaths**
Country	**Hazard Zone**	**N (Z)**	depth	velocity	DF	**HR**	Speed of onset	Nature of area	Flood warning	**AV**	% of long term ill	% of very old	**PV**			
Ita	Fella a	400	2.5	3.0	1	9.8	2	2	2	6		10%	10%	47	9	1
Ita	Fella b	500	3.0	3.0	1	11.5	2	1	2	5		10%	10%	58	13	1
Ita	Cassano Murge	20,000	3.0	5.0	1	17.5	3	1	3	7		9%	9%	4,263	1,492	7
Ita	Fortezza	60	4.0	9.0	1	39.0	3	1	3	7		2%	2%	7	5	1
Spa	Calonge	1,300	1.0	2.5		3.0	3	3	1	7		25%	25%	137	8	1
Spa	La Farinera	200	2.0	2.5		6.0	3	3	3	9	1%	15%	16%	33	4	4
Spa	Magarola	300	5.0	9.0		47.5	2	2	3	7		8%	8%	160	152	7
Spa	Cambrils	2,000	3.0	1.5		6.0	2	3	1	6		1%	1%	14	2	1
Pol	Duszniki zdroj zone c	120	4.0	10.0	1	43.0	2	3	3	8		8%	8%	66	57	1
Pol	Klodzko gmina zone c	1,050	3.8	5.0	1	21.9	2	1	3	6		8%	8%	210	92	5
Pol	Klodzko town zone a	200	4.0	5.0	1	23.0	2	2	3	7		9%	9%	58	27	1
Pol	Klodzko town zone c	2,500	6.5	10.0	1	69.3	2	1	3	6		6%	6%	1,330	1,841	1
Pol	Miedzylesie zone b	876	2.0	5.0	1	12.0	2	2	3	7		9%	9%	134	32	2
Pol	Stronie Slaskie zone a	2,000	4.0	10.0	1	43.0	2	3	3	8		6%	6%	826	710	1
Cze	Olomouc	28,200	2.0	0.4	1	2.8	1	2	1	4		6%	6%	384	22	5
Cze	Otrokovice	19,000	3.5	0.3	1	3.9	1	2	1	4		7%	7%	389	31	3
Cze	Troubky	2,010	2.0	0.3	1	2.6	2	2	3	7		5%	5%	37	2	9
Ger	Dresden	300	1.8	4.0	1	9.1	2	3	3	8		10%	10%	44	8	1
Ger	Erlln	100	1.6	4.0	0.5	7.7	2	2	2	6		5%	5%	5	1	0
Ger	Grimma	1,200	3.0	7.0	0.5	23.0	2	2	2	6		9%	9%	285	131	0
Ger	Eilenburg	275	2.0	4.0	1	10.0	3	2	1	6		8%	8%	27	5	0
Pol	Bystrzyca Klodzka	450	5.0	10.0	1	53.5	2	3	3	8		5%	5%	193	206	0
Pol	Stronie Slaskie zone b	400	2.0	10.0	1	22.0	2	1	3	6		25%	25%	264	116	0
Pol	Polanica Zdroj	420	5.0	10.0	1	53.5	2	3	2	7		7%	7%	220	236	0
Pol	Miedzylesie zone c	138	1.5	10.0	1	16.8	2	1	3	6		9%	9%	25	8	0
Pol	Miedzylesie zone a	369	2.5	10.0	1	27.3	2	3	3	8		9%	9%	145	79	0
Pol	Ladek Zdroj zone d	300	2.0	5.0	1	12.0	2	2	1	5		7%	7%	25	6	0
Pol	Ladek Zdroj zone b	250	4.6	5.0	1	26.3	2	3	1	6		8%	8%	63	33	0
Pol	Ladek Zdroj zone a	180	3.0	5.0	1	17.5	2	1	1	4		8%	8%	20	7	0
Pol	Duszniki zdroj zone b	450	4.0	10.0	1	43.0	2	3	3	8		33%	33%	1,022	879	0
Pol	Klodzko gmina zone a	120	2.0	5.0	1	12.0	2	1	3	6		8%	8%	14	3	0
Pol	Bystrzyca Klodzka zone b	1,050	2.0	5.0	1	12.0	2	1	3	6		6%	6%	91	22	0
Pol	Klodzko town zone d	30	4.0	5.0	1	23.0	2	2	3	7		16%	16%	15	7	0
Pol	Klodzko gmina zone b	100	3.8	5.0	1	21.9	2	1	3	6		7%	7%	18	8	0

Appendix E: Principal Component Analysis (PCA) results

ALL DATA INCLUDING UK

Eigenanalysis of the Correlation Matrix

29 cases used, 16 cases contain missing values

Eigenvalue	4.9906	3.2313	2.9594	2.2313	1.5689	1.5023	1.1472	0.9361
Proportion	0.227	0.147	0.135	0.101	0.071	0.068	0.052	0.043
Cumulative	0.227	0.374	0.508	0.61	0.681	0.749	0.801	0.844
Eigenvalue	0.7988	0.5701	0.5273	0.4291	0.3593	0.2802	0.1596	0.1284
Proportion	0.036	0.026	0.024	0.02	0.016	0.013	0.007	0.006
Cumulative	0.88	0.906	0.93	0.95	0.966	0.979	0.986	0.992
Eigenvalue	0.0835	0.0508	0.0326	0.0117	0.0015	0		
Proportion	0.004	0.002	0.001	0.001	0	0		
Cumulative	0.996	0.998	0.999	1	1	1		

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N (Z)	0.287	0.07	0.197	0.049	-0.321	-0.181	-0.043
depth	-0.146	-0.089	0.046	0.258	0.118	-0.545	0.035
velocity	-0.315	-0.01	0.018	0.165	0.255	-0.225	0.144
DF	-0.027	0.263	0.158	-0.451	-0.016	-0.265	0.037
Speed of onset	-0.261	-0.13	-0.253	-0.17	-0.278	-0.059	0.111
Nature of area	0.011	0.037	0.002	0.197	0.412	0.009	-0.477
Flood warning	-0.269	-0.17	0.205	-0.111	0.089	-0.17	0.043
% of very old	-0.08	0.232	-0.031	-0.195	0.195	-0.065	-0.537
Actual Deaths	-0.004	-0.392	0.151	-0.07	-0.324	-0.192	-0.198
Awareness of flood risk	0.035	0.009	0.354	0.09	0.394	-0.064	0.26
Building collapse 1	0.042	-0.054	0.301	-0.179	0.189	0.219	0.48
Building collapse 2	0.225	-0.294	0.211	-0.289	0.024	0.104	-0.173
Building Collapse 3	0.129	-0.376	0.155	-0.317	0.112	0.11	-0.138
Evacuation 1	0.285	-0.11	-0.268	-0.13	0.196	-0.085	0.057
Evacuation 2 (after)	0.167	-0.421	-0.033	0.137	0.217	-0.063	-0.025
Evacuation 3 (before)	0.053	0.076	-0.448	-0.282	0.087	-0.202	0.145
Evacuation 4 (general)	0.171	-0.274	-0.362	-0.104	0.235	-0.201	0.089
Flood Duration (hours)	0.335	0.102	-0.102	-0.015	-0.052	-0.275	0.14
Population with language constraints	-0.02	-0.302	-0.164	0.404	-0.176	0.165	0.035
Time of the Flood	-0.21	-0.157	0.204	-0.062	-0.16	-0.386	-0.067
Actual Speed of onset (minutes)	0.363	0.162	0.165	0.187	-0.048	-0.122	-0.001
Time of flood warning before the flood	0.386	0.096	0.093	0.156	-0.079	-0.205	-0.004

ALL DATA MINUS CZECH

Eigenanalysis of the Correlation Matrix26 cases used, 16 cases contain missing values

Eigenvalue	4.2614	3.5829	3.096	2.1573	1.7862	1.3368	1.2367	1.0445
Proportion	0.194	0.163	0.141	0.098	0.081	0.061	0.056	0.047
Cumulative	0.194	0.357	0.497	0.595	0.677	0.737	0.794	0.841
Eigenvalue	0.8507	0.665	0.5899	0.4063	0.341	0.2477	0.1563	0.1153
Proportion	0.039	0.03	0.027	0.018	0.015	0.011	0.007	0.005
Cumulative	0.88	0.91	0.937	0.955	0.971	0.982	0.989	0.994
Eigenvalue	0.0531	0.0403	0.0193	0.0101	0.0034	0		
Proportion	0.002	0.002	0.001	0	0	0		
Cumulative	0.997	0.999	0.999	1	1	1		

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N (Z)	-0.125	-0.05	-0.186	-0.397	0.11	-0.135	-0.064
depth	-0.121	0.108	-0.268	0.102	-0.426	0.184	0.176
velocity	-0.152	0.183	-0.148	0.12	-0.442	-0.023	0.082
DF	-0.21	-0.144	0.319	-0.218	-0.315	0.035	-0.091
Speed of onset	0.018	-0.263	-0.222	-0.418	0.003	-0.158	0.14
Nature of area	0.026	0.083	0.072	0.345	0.01	0.067	0.615
Flood warning	-0.277	0.157	-0.099	-0.013	-0.233	-0.174	-0.249
% of very old	-0.065	-0.079	0.242	0.061	-0.153	0.448	-0.119
Actual Deaths	-0.176	-0.006	-0.416	-0.183	0.083	-0.037	0.046
Awareness of flood risk	-0.095	0.289	0.114	0.089	-0.157	-0.457	0.12
Building collapse 1	0.016	0.289	0.197	-0.151	-0.155	-0.255	-0.242
Building collapse 2	0.288	0.338	0.004	-0.257	-0.11	0.154	-0.018
Building Collapse 3	0.274	0.359	0.047	-0.256	-0.11	0.115	-0.046
Evacuation 1	0.341	-0.157	-0.038	0.117	-0.233	0.091	-0.273
Evacuation 2 (after)	0.165	0.108	-0.364	0.311	-0.043	-0.179	-0.254
Evacuation 3 (before)	0.234	-0.383	0.071	-0.029	-0.27	-0.124	0.092
Evacuation 4 (general)	0.302	-0.229	-0.199	0.195	-0.245	-0.224	-0.104
Flood Duration (hours)	0.259	-0.202	0.096	-0.178	-0.153	-0.312	0.339
Population with language constraints	0.209	0.168	-0.398	-0.005	0.189	0.157	0.057
Time of the Flood	-0.28	0.045	-0.166	-0.168	-0.224	0.097	0.278
Actual Speed of onset (minutes)	0.096	0.267	0.213	0.067	0.209	-0.318	0.119
Time of flood warning before the flood	0.366	0.19	0.02	-0.254	-0.111	0.191	0.175

EUROPEAN DATA
Eigenanalysis of the Correlation Matrix
29 cases used, 5 cases contain missing values

Eigenvalue	4.9906	3.2313	2.9594	2.2313	1.5689	1.5023	1.1472	0.9361
Proportion	0.227	0.147	0.135	0.101	0.071	0.068	0.052	0.043
Cumulative	0.227	0.374	0.508	0.61	0.681	0.749	0.801	0.844
Eigenvalue	0.7988	0.5701	0.5273	0.4291	0.3593	0.2802	0.1596	0.1284
Proportion	0.036	0.026	0.024	0.02	0.016	0.013	0.007	0.006
Cumulative	0.88	0.906	0.93	0.95	0.966	0.979	0.986	0.992
Eigenvalue	0.0835	0.0508	0.0326	0.0117	0.0015	0		
Proportion	0.004	0.002	0.001	0.001	0	0		
Cumulative	0.996	0.998	0.999	1	1	1		

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N (Z)	0.287	0.07	0.197	0.049	-0.321	-0.181	-0.043
depth	-0.146	-0.089	0.046	0.258	0.118	-0.545	0.035
velocity	-0.315	-0.01	0.018	0.165	0.255	-0.225	0.144
DF	-0.027	0.263	0.158	-0.451	-0.016	-0.265	0.037
Speed of onset	-0.261	-0.13	-0.253	-0.17	-0.278	-0.059	0.111
Nature of area	0.011	0.037	0.002	0.197	0.412	0.009	-0.477
Flood warning	-0.269	-0.17	0.205	-0.111	0.089	-0.17	0.043
% of very old	-0.08	0.232	-0.031	-0.195	0.195	-0.065	-0.537
Actual Deaths	-0.004	-0.392	0.151	-0.07	-0.324	-0.192	-0.198
Awareness of flood risk	0.035	0.009	0.354	0.09	0.394	-0.064	0.26
Building collapse 1	0.042	-0.054	0.301	-0.179	0.189	0.219	0.48
Building collapse 2	0.225	-0.294	0.211	-0.289	0.024	0.104	-0.173
Building Collapse 3	0.129	-0.376	0.155	-0.317	0.112	0.11	-0.138
Evacuation 1	0.285	-0.11	-0.268	-0.13	0.196	-0.085	0.057
Evacuation 2 (after)	0.167	-0.421	-0.033	0.137	0.217	-0.063	-0.025
Evacuation 3 (before)	0.053	0.076	-0.448	-0.282	0.087	-0.202	0.145
Evacuation 4 (general)	0.171	-0.274	-0.362	-0.104	0.235	-0.201	0.089
Flood Duration (hours)	0.335	0.102	-0.102	-0.015	-0.052	-0.275	0.14
Population with language constraints	-0.02	-0.302	-0.164	0.404	-0.176	0.165	0.035
Time of the Flood	-0.21	-0.157	0.204	-0.062	-0.16	-0.386	-0.067
Actual Speed of onset (minutes)	0.363	0.162	0.165	0.187	-0.048	-0.122	-0.001
Time of flood warning before the flood	0.386	0.096	0.093	0.156	-0.079	-0.205	-0.004

EUROPEAN DEATHS MINUS CZECH

Eigenanalysis of the Correlation Matrix
26 cases used, 5 cases contain missing values

Eigenvalue	4.2614	3.5829	3.096	2.1573	1.7862	1.3368	1.2367	1.0445
Proportion	0.194	0.163	0.141	0.098	0.081	0.061	0.056	0.047
Cumulative	0.194	0.357	0.497	0.595	0.677	0.737	0.794	0.841
Eigenvalue	0.8507	0.665	0.5899	0.4063	0.341	0.2477	0.1563	0.1153
Proportion	0.039	0.03	0.027	0.018	0.015	0.011	0.007	0.005
Cumulative	0.88	0.91	0.937	0.955	0.971	0.982	0.989	0.994
Eigenvalue	0.0531	0.0403	0.0193	0.0101	0.0034	0		
Proportion	0.002	0.002	0.001	0	0	0		
Cumulative	0.997	0.999	0.999	1	1	1		

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N (Z)	-0.125	-0.05	-0.186	-0.397	0.11	-0.135	-0.064
depth	-0.121	0.108	-0.268	0.102	-0.426	0.184	0.176
velocity	-0.152	0.183	-0.148	0.12	-0.442	-0.023	0.082
DF	-0.21	-0.144	0.319	-0.218	-0.315	0.035	-0.091
Speed of onset	0.018	-0.263	-0.222	-0.418	0.003	-0.158	0.14
Nature of area	0.026	0.083	0.072	0.345	0.01	0.067	0.615
Flood warning	-0.277	0.157	-0.099	-0.013	-0.233	-0.174	-0.249
% of very old	-0.065	-0.079	0.242	0.061	-0.153	0.448	-0.119
Actual Deaths	-0.176	-0.006	-0.416	-0.183	0.083	-0.037	0.046
Awareness of flood risk	-0.095	0.289	0.114	0.089	-0.157	-0.457	0.12
Building collapse 1	0.016	0.289	0.197	-0.151	-0.155	-0.255	-0.242
Building collapse 2	0.288	0.338	0.004	-0.257	-0.11	0.154	-0.018
Building Collapse 3	0.274	0.359	0.047	-0.256	-0.11	0.115	-0.046
Evacuation 1	0.341	-0.157	-0.038	0.117	-0.233	0.091	-0.273
Evacuation 2 (after)	0.165	0.108	-0.364	0.311	-0.043	-0.179	-0.254
Evacuation 3 (before)	0.234	-0.383	0.071	-0.029	-0.27	-0.124	0.092
Evacuation 4 (general)	0.302	-0.229	-0.199	0.195	-0.245	-0.224	-0.104
Flood Duration (hours)	0.259	-0.202	0.096	-0.178	-0.153	-0.312	0.339
Population with language constraints	0.209	0.168	-0.398	-0.005	0.189	0.157	0.057
Time of the Flood	-0.28	0.045	-0.166	-0.168	-0.224	0.097	0.278
Actual Speed of onset (minutes)	0.096	0.267	0.213	0.067	0.209	-0.318	0.119
Time of flood warning before the flood	0.366	0.19	0.02	-0.254	-0.111	0.191	0.175

EUROPEAN DEATHS

Eigenanalysis of the Correlation Matrix
15 cases used, 3 cases contain missing values

Eigenvalue	5.9492	3.362	2.9777	2.1612	1.3553	1.197	0.6787	0.5188
Proportion	0.313	0.177	0.157	0.114	0.071	0.063	0.036	0.027
Cumulative	0.313	0.49	0.647	0.761	0.832	0.895	0.931	0.958
Eigenvalue	0.4246	0.2555	0.0666	0.0291	0.0201	0.0043	0	0
Proportion	0.022	0.013	0.004	0.002	0.001	0	0	0
Cumulative	0.98	0.994	0.997	0.999	1	1	1	1
Eigenvalue	0	0	0	0				
Proportion	0	0	0	0				
Cumulative	1	1	1	0				

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
N (Z)	0.272	0.066	0.204	0.03	0.328	-0.028	-0.514	-0.013	-0.449
depth	-0.166	0.123	0.09	-0.489	0.175	-0.165	0.426	-0.119	-0.25
velocity	-0.309	0.102	0.063	-0.312	-0.078	-0.205	0.006	-0.122	-0.108
Speed of onset	-0.343	-0.008	-0.07	0.03	0.223	0.187	-0.415	0.15	0.252
Nature of area	0.098	0.069	0.024	0.107	-0.704	0.377	0.12	0.088	-0.201
Flood warning	-0.3	0.185	-0.164	0.008	-0.052	-0.331	-0.145	0.375	0.205
% of very old	0.007	-0.428	-0.055	0.17	-0.029	-0.365	0.102	0.486	-0.221
Awareness of flood risk	0.089	0.428	0.074	0.007	-0.208	-0.298	-0.122	0.362	-0.362
Building collapse 1	0.056	0.248	-0.047	0.374	-0.048	-0.527	0.147	-0.411	0.178
Building collapse 2	0.187	0.208	-0.326	0.293	0.211	0.053	0.068	-0.161	-0.236
Building Collapse 3	0.087	0.217	-0.427	0.243	0.166	0.111	0.216	0.212	0.116
Evacuation 1	0.285	-0.187	-0.318	-0.159	0.098	-0.06	-0.009	-0.098	-0.169
Evacuation 2 (after)	0.116	0.181	-0.404	-0.359	-0.108	0.027	-0.162	0.008	0.052
Evacuation 3 (before)	-0.001	-0.509	-0.158	0.032	0.074	-0.091	0.181	0.049	-0.118
Evacuation 4 (general)	0.116	0.003	-0.461	-0.349	-0.083	-0.005	-0.099	0.025	0.011
Flood Duration (hours)	0.339	0.093	0.165	-0.146	0.123	-0.024	0.232	0.315	0.344
Time of the Flood	-0.224	0.269	0.051	0.078	0.346	0.332	0.343	0.237	-0.231
Actual Speed of onset (minutes)	0.357	0.053	0.229	-0.088	-0.022	-0.071	-0.039	0.047	0.215
Time of flood warning before the flood	0.362	0.039	0.174	-0.157	0.144	0.017	0.084	0.15	0.187

EUROPEAN DEATHS CONTD

Variable	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18
N (Z)	0.114	0.27	-0.016	0.05	-0.196	0.163	-0.22	0.218	-0.207
depth	-0.028	0.32	0.045	-0.521	-0.089	0.014	0.036	-0.041	-0.071
velocity	0.616	0.005	-0.271	0.431	0.216	-0.055	-0.039	0.077	0.144
Speed of onset	0.076	0.52	0.033	-0.108	-0.018	-0.217	0.256	-0.187	0.282
Nature of area	0.274	0.342	0.093	-0.04	-0.266	0.005	0.009	-0.009	-0.021
Flood warning	0.286	-0.25	0.287	-0.164	-0.386	0.161	-0.073	0.076	-0.284
% of very old	0.033	0.116	0.02	-0.028	0.084	-0.064	-0.077	-0.208	0.2
Awareness of flood risk	-0.292	-0.034	-0.149	0.026	0.207	-0.129	0.242	-0.04	0.105
Building collapse 1	-0.104	0.385	0.128	0.256	-0.193	-0.006	0.013	-0.099	0.019
Building collapse 2	0.36	-0.231	0.065	-0.313	-0.018	-0.068	-0.185	-0.118	0.488
Building Collapse 3	0.142	0.246	-0.392	-0.074	0.316	0.101	0.066	0.161	-0.412
Evacuation 1	0.16	-0.107	0.188	0.137	-0.186	-0.318	0.665	0.084	-0.165
Evacuation 2 (after)	-0.177	0.049	0.082	0.103	0.014	0.614	0.12	-0.009	0.331
Evacuation 3 (before)	0.032	0.21	0.046	0.164	0.001	0.361	-0.053	0.113	0.046
Evacuation 4 (general)	-0.166	0.122	0.098	0.161	0.014	-0.441	-0.555	-0.151	-0.148
Flood Duration (hours)	0.023	0.103	-0.05	0.075	-0.23	-0.19	-0.081	0.542	0.364
Time of the Flood	-0.087	-0.014	0.401	0.471	-0.043	0.025	-0.01	-0.123	-0.016
Actual Speed of onset (minutes)	0.275	0.111	0.553	-0.086	0.568	0.065	0.003	-0.108	-0.104
Time of flood warning before the flood	0.167	-0.038	-0.335	0.112	-0.296	0.133	0.03	-0.668	-0.082

EUROPEAN DEATHS (without Czech) Contd.

Eigenanalysis of the Correlation Matrix
12 cases used, 3 cases contain missing values

Eigenvalue	5.3258	3.6135	3.0009	2.2522	2.0504	0.9499	0.8048	0.5087
Proportion	0.28	0.19	0.158	0.119	0.108	0.05	0.042	0.027
Cumulative	0.28	0.47	0.628	0.747	0.855	0.905	0.947	0.974

Eigenvalue	0.2888	0.1797	0.0254	0	0	0	0	0
Proportion	0.015	0.009	0.001	0	0	0	0	0
Cumulative	0.989	0.999	1	1	1	1	1	1

Eigenvalue	0	0	0	0
Proportion	0	0	0	0
Cumulative	1	1	1	0

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
N (Z)	0.019	-0.22	0.214	0.314	0.073	0.656	-0.064	-0.025	-0.356
depth	0.104	-0.312	-0.157	-0.421	0.193	-0.007	-0.115	0.085	-0.258
velocity	0.15	-0.336	-0.256	-0.073	0.1	-0.369	-0.262	-0.186	-0.384
Speed of onset	-0.014	-0.354	0.223	0.361	0.073	-0.081	0.086	0.362	-0.126
Nature of area	0.002	0.19	-0.07	-0.043	-0.604	-0.08	-0.102	-0.346	-0.251
Flood warning	0.246	-0.162	-0.232	0.233	0.177	-0.112	-0.461	0.036	0.268
% of very old	-0.198	0.302	0.067	0.089	0.305	0.116	-0.51	-0.188	0.003
Awareness of flood risk	0.321	-0.036	-0.19	0.026	-0.146	0.464	-0.213	-0.306	0.112
Building collapse 1	0.329	0.258	-0.113	0.055	0.212	0.002	0.167	0.101	-0.245
Building collapse 2	0.307	0.134	-0.079	-0.098	0.377	0.038	0.284	-0.198	-0.211
Building Collapse 3	0.299	0.287	-0.115	0.165	0.168	-0.02	0.276	-0.065	0.099
Evacuation 1	-0.361	0.072	-0.259	-0.058	0.171	0.092	-0.037	0.079	-0.011
Evacuation 2 (after)	-0.105	-0.174	-0.487	-0.048	-0.112	0.229	0.177	0.135	0.115
Evacuation 3 (before)	-0.342	0.212	0.061	-0.032	0.282	-0.063	-0.175	-0.008	-0.098
Evacuation 4 (general)	-0.237	-0.086	-0.45	-0.059	0.002	0.198	0.104	0.128	0.073
Flood Duration (hours)	0.295	0.18	0.067	-0.321	0.019	0.14	-0.221	0.39	0.333
Time of the Flood	0.194	-0.303	0.318	-0.198	-0.06	-0.016	-0.052	-0.068	0.248
Actual Speed of onset (minutes)	0.177	0.278	-0.131	0.165	-0.303	-0.047	-0.258	0.554	-0.341
Time of flood warning before the flood	-0.039	0.068	0.222	-0.552	-0.007	0.225	-0.03	0.135	-0.251

EUROPEAN DEATHS (without Czech) Contd.

Variable	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18
N (Z)	-0.138	-0.11	-0.139	-0.042	0.324	-0.011	0.095	0.258	-0.054
depth	-0.21	0.117	0.094	-0.024	0.232	-0.11	-0.204	-0.4	-0.108
velocity	-0.027	0.019	-0.288	-0.016	-0.069	0.053	0.446	0.141	0.119
Speed of onset	0.186	-0.37	-0.001	0.041	-0.338	-0.056	0.03	-0.471	0.12
Nature of area	-0.017	-0.583	0.021	-0.013	0.08	-0.027	-0.061	-0.126	-0.035
Flood warning	0.396	-0.238	0.23	-0.081	0.279	-0.025	-0.271	0.195	-0.109
% of very old	-0.041	-0.02	0.182	0.301	-0.335	-0.027	0.32	-0.087	-0.15
Awareness of flood risk	0.044	0.25	-0.035	-0.142	-0.27	0.03	-0.152	-0.409	0.217
Building collapse 1	-0.093	-0.123	0.221	-0.291	-0.149	0.681	0.007	0.016	-0.138
Building collapse 2	-0.017	-0.24	-0.043	0.342	-0.255	-0.355	-0.36	0.226	0.094
Building Collapse 3	0.027	-0.045	0.111	-0.079	0.405	-0.343	0.496	-0.337	-0.034
Evacuation 1	-0.155	-0.199	-0.167	-0.441	-0.156	-0.247	-0.1	-0.075	-0.506
Evacuation 2 (after)	0.016	-0.107	0.03	0.619	0.082	0.271	0.114	-0.088	-0.257
Evacuation 3 (before)	-0.192	-0.152	0.055	0.113	0.374	0.21	-0.211	-0.236	0.45
Evacuation 4 (general)	-0.06	-0.164	0.309	-0.248	-0.153	-0.137	0.192	0.231	0.538
Flood Duration (hours)	-0.139	-0.322	-0.52	0.012	-0.006	0.05	0.126	0.031	0.138
Time of the Flood	-0.493	-0.195	0.495	0.014	-0.071	-0.051	0.125	0.087	-0.105
Actual Speed of onset (minutes)	-0.198	0.242	0.198	0.131	-0.036	-0.258	-0.077	0.078	0
Time of flood warning before the flood	0.603	-0.04	0.235	-0.041	0.014	-0.033	0.168	0.023	-0.034

Appendix F: Statistically significant relationships taken from the correlation matrices of the data

ALL DATA (EUROPEAN AND UK DATA) **N=45, Deaths =92 (24 observations with deaths; 21 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Depth	Velocity	0.658	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity
Depth	% of long term ill	-0.492	0.001	No relevant relationship
Velocity	% of long term ill	-0.513	0.001	No relevant relationship
Nz	Building Collapse 2	0.361	0.017	No relevant relationship
Velocity	Building Collapse 2	-0.268	0.082	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the numbers of buildings that collapse decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 2	Building Collapse 3	0.405	0.007	Covariance
Evacuation (after)	Building Collapse 2	0.423	0.008	This correlation indicates basically that more people are evacuated from an area after the event where there are higher numbers of buildings that have collapsed. This is an obvious and sensible relationship as either they have no longer anywhere to reside or more likely there is the concern over more building collapses. A higher correlation than 0.423 might have been expected. However, it must be remembered that in this only official evacuation is included and people may also take it upon themselves to vacate an area.
Evacuation (before)	Evacuation (general)	0.681	0.000	Covariance
Evacuation (after)	Evacuation (general)	0.651	0.000	Covariance
Flood Duration	Nz	0.42	0.006	No relevant relationship
Flood Duration	Velocity	-0.275	0.078	Although not really that strong or interesting a relationship the correlation here again relating to different flood characteristics. The relationship is suggesting that longer lasting floods typically have lower velocities. Although there is some variation, typically the velocity is higher with quick-onset and high velocity flooding, than floods with slower onsets which typically have slower velocities.
Flood Duration	Evacuation (before)	0.374	0.016	This is a relatively weak correlation and although makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood Duration	Evacuation (general)	0.402	0.014	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.
Actual speed of onset	Nz	0.715	0.000	No relevant relationship
Actual speed of onset	Velocity	-0.353	0.032	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Duration	0.671	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.

ALL DATA (EUROPEAN AND UK DATA) Contd.				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Time of flood warning	Nz	0.692	0.000	No relevant relationship
Time of flood warning	Velocity	-0.376	0.022	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time of flood warning	Evacuation (general)	0.762	0.000	An expected relationship. Those events which have a longer time between the flood warning and the flooding (i.e. those events with sufficient time to warn) have a higher instance of evacuation.
Time of flood warning	Actual speed of onset	0.922	0.000	This relationship implies that those events that have a longer lead time also have a longer time between the flood warning and the flood.
Death	**Building Collapse 2**	**0.278**	**0.071**	**An obvious and very interesting relationship that more deaths occur when there are more building collapses. Although the correlation between these variables is not that strong.**
Death	**Building Collapse 3**	**0.897**	**0.000**	**Again the same relationship as above although the correlation in this case is much more significant. In this instance the relationship is related to the ratio between building collapse and population size. This is potentially being skewed by the Lynmouth event as this had a low population of 100 and 39 buildings that collapsed.**

ALL DATA (EUROPEAN AND UK DATA BUT WITHOUT LYNMOUTH ZONE 1) **N=44, Deaths =64 (23 observations with deaths; 21 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.66	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Depth	-0.492	0.001	No relevant relationship
% of long term ill	Velocity	-0.513	0.001	No relevant relationship
Building Collapse 2	NZ	0.366	0.017	No relevant relationship
Building Collapse 2	Velocity	-0.267	0.088	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the numbers of buildings that collapse decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 3	Building Collapse 2	0.861	0.000	Covariance
Evacuation (after)	Building Collapse 2	0.427	0.008	This correlation indicates basically that more people are evacuated from an area after the event where there are higher numbers of buildings that have collapsed. This is an obvious and sensible relationship as either they have no longer anywhere to reside or more likely there is the concern over more building collapses. A higher correlation than shown might have been expected. However, it must be remembered that this only official evacuation is included and people may also take it upon themselves to vacate an area.
Evacuation (after)	Building Collapse 3	0.51	0.001	This correlation indicates basically that more people are evacuated from an area after the event where there is a higher ration between building collapse and population at risk. See above for explanation.

ALL DATA (EUROPEAN AND UK DATA BUT WITHOUT LYNMOUTH ZONE 1) Contd.				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Evacuation (general)	Building Collapse 3	0.323	0.051	Similar to the relationship described above it would make sense that more people will be evacuated from an area where there is a higher degree of building collapse.
Evacuation (general)	Evacuation (after)	0.68	0.000	Covariance
Evacuation (general)	Evacuation (before)	0.649	0.000	Covariance
Flood duration	NZ	0.417	0.007	No relevant relationship
Flood duration	Velocity	-0.281	0.076	Although not really that strong or interesting a relationship the correlation here again relating to different flood characteristics. The relationship is suggesting that as velocity increases the flood duration gets less. Although there is some variation, typically the velocity is higher with quick-onset and high velocity flooding, than floods with slower onsets which typically have slower velocities.
Flood duration	Evacuation (before)	0.371	0.018	This is a relatively weak correlation and although makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood duration	Evacuation (general)	0.396	0.017	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.
Actual speed of onset	Nz	0.714	0.000	No relevant relationship
Actual speed of onset	Velocity	-0.361	0.031	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Flood duration	0.699	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	Nz	0.691	0.000	No relevant relationship
Time to flood warning	Velocity	-0.383	0.021	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Flood duration	0.761	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.922	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**Nz**	**0.249**	**0.103**	**Not a very strong relationship here, but an obvious and well-documented one. As population at risk increases so do the number of deaths.**
Death	**Building Collapse 2**	**0.469**	**0.002**	**An obvious and very interesting relationship that more deaths occur when there are more building collapses. The correlation coefficient is strengthened with the removal of the Lynmouth 1 data.**
Death	**Building Collapse 3**	**0.487**	**0.001**	**The relationship is the same as above i.e. the higher instance of buildings collapsing the more deaths will result. The correlation is not as high as the previous set of data as the influence of Lynmouth 1 has been removed.**
Death	**Evacuation (after)**	**0.405**	**0.013**	**An explanation of this relationship is difficult as one might argue that the more people that are evacuated then the lower the likely death toll. The relationship does not seem that simple however. There is a statistically significant relationship between building collapse and evacuation and therefore this relationship might not be important and may be is being created as a function of the building collapse element. Secondly, it might merely be an indicator of the severity of the event. i.e. if many deaths have already occurred (through whatever mechanism, but mainly through building collapse) then it is sensible to evacuate large numbers after the flooding has peaked to prevent more deaths.**

ALL DATA (EUROPEAN AND UK DATA BUT WITHOUT LYNMOUTH ZONE 1 AND TROUBKY) **N=43, Deaths =55 (22 observations with deaths; 21 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.659	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Depth	-0.502	0.001	No relevant relationship
% of long term ill	Velocity	-0.540	0.000	No relevant relationship
Building Collapse 2	NZ	0.684	0.000	No relevant relationship
Building Collapse 3	Building Collapse 2	0.341	0.029	Covariance
Evacuation (general)	Evacuation (after)	0.627	0.000	Covariance
Evacuation (general)	Evacuation (before)	0.715	0.000	Covariance
Flood duration	NZ	0.418	0.007	No relevant relationship
Flood duration	Evacuation (after)	0.376	0.018	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered.
Flood duration	Evacuation (before)	0.401	0.017	This makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Actual speed of onset	NZ	0.715	0.000	No relevant relationship
Actual speed of onset	Velocity	-0.396	0.018	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Building Collapse 2	0.502	0.002	
Actual speed of onset	Flood duration	0.675	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	NZ	0.692	0.000	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.389	0.021	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Building Collapse 2	0.437	0.009	No relevant relationship
Time to flood warning	Flood duration	0.761	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.927	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**NZ**	**0.297**	**0.053**	**Not a very strong relationship here, but an obvious and well-documented one. As population at risk increases so do the number of deaths.**
Death	**Depth**	**0.287**	**0.062**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**

ALL DATA (EUROPEAN AND UK DATA BUT WITHOUT LYNMOUTH ZONE 1 and NO CZECH) **N=44, Deaths =64 (23 observations with deaths; 21 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.695	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Depth	-0.509	0.001	No relevant relationship
% of long term ill	Velocity	-0.604	0.000	No relevant relationship
Building Collapse 3	Building Collapse 2	0.962	0.000	Covariance
Evacuation (general)	Evacuation (after)	0.617	0.000	Covariance
Evacuation (general)	Evacuation (before)	0.733	0.000	Covariance
Flood duration	Evacuation (before)	0.625	0.000	This makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood duration	Evacuation (general)	0.461	0.007	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.
Actual speed of onset	Building Collapse 2	0.334	0.058	No relevant relationship
Actual speed of onset	Building Collapse 3	0.357	0.042	No relevant relationship
Time to flood warning	Building Collapse 2	0.885	0.000	No relevant relationship
Time to flood warning	Building Collapse 3	0.833	0.000	No relevant relationship
Time to flood warning	Flood duration	0.400	0.021	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Death	**Nz**	**0.505**	**0.001**	**An obvious and well-documented relationship. That as population at risk increases so do the number of deaths.**
Death	**Depth**	**0.297**	**0.060**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**
Death	**Flood duration**	**-0.286**	**0.082**	**This correlation is indicating that there is a negative (although quite weak) relationship between the numbers of people who are killed and the duration of the flood. This is indicating that shorter floods have more deaths. It is important to note at this stage that the slow onset floods with very deep waters have been omitted from this analysis and therefore this might be suggesting that people are more likely to be killed in floods with a flasher regime.**

EUROPEAN DATA **N=34, Deaths =52 (18 observations with deaths; 16 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	NZ	-0.392	0.022	No relevant relationship
Velocity	Depth	0.491	0.003	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Velocity	-0.296	0.090	No relevant relationship
Building Collapse 2	Velocity	-0.402	0.019	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the numbers of buildings that collapse decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 3	Velocity	-0.287	0.099	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the ration between numbers of buildings that collapse and population decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 3	Building Collapse 2	0.859	0.00	Covariance
Evacuation (after)	Building Collapse 2	0.414	0.025	This correlation indicates basically that more people are evacuated from an area after the event where there are higher numbers of buildings that have collapsed. This is an obvious and sensible relationship as either they have no longer anywhere to reside or more likely there is the concern over more building collapses. A higher correlation than shown might have been expected. However, it must be remembered that this only official evacuation is included and people may also take it upon themselves to vacate an area.
Evacuation (after)	Building Collapse 3	0.500	0.006	This correlation indicates basically that more people are evacuated from an area after the event where there is a higher ration between building collapse and population at risk. See above for explanation.
Evacuation (general)	Evacuation (after)	0.671	0.000	Covariance
Evacuation (general)	Evacuation (before)	0.631	0.000	Covariance
Flood duration	NZ	0.411	0.016	No relevant relationship
Flood duration	Velocity	-0.374	0.029	Although not really that strong or interesting a relationship the correlation here again relating to different flood characteristics. The relationship is suggesting that longer lasting floods typically have lower velocities. Although there is some variation, typically the velocity is higher with quick-onset and high velocity flooding, than floods with slower onsets which typically have slower velocities.
Flood duration	Evacuation (before)	0.365	0.037	This is a relatively weak correlation and although makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood duration	Evacuation (general)	0.392	0.036	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.
Actual speed of onset	Nz	0.711	0.000	No relevant relationship

EUROPEAN DATA (contd) N=34, Deaths =52 (18 observations with deaths; 16 observations with no deaths)				
Actual speed of onset	Velocity	-0.399	0.019	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Flood duration	0.664	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	Nz	0.689	0.000	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.417	0.014	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Flood duration	0.759	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.921	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**% of population over 75**	**-0.294**	**0.092**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**
Death	**Building Collapse 2**	**0.480**	**0.004**	**An obvious and very interesting relationship that more deaths occur when there are more building collapses. Although the correlation between these variables is not that strong.**
Death	**Building Collapse 3**	**0.499**	**0.003**	**Again the same relationship as above although the correlation in this case is much more significant. In this instance the relationship is related to the ratio between building collapse and population size.**
Death	**Evacuation (after)**	**0.408**	**0.028**	**An explanation of this relationship is difficult as one might argue that the more people that are evacuated then the lower the likely death toll. The relationship does not seem that simple however. There is a statistically significant relationship between building collapse and evacuation and therefore this relationship might not be important and may be is being created as a function of the building collapse element. Secondly, it might merely be an indicator of the severity of the event. i.e. if many deaths have already occurred (through whatever mechanism, but mainly through building collapse) then it is sensible to evacuate large numbers after the flooding has peaked to prevent more deaths.**

EUROPEAN DATA (NO TROUBKY) **N=33, Deaths =43 (17 observations with deaths; 16 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	NZ	-0.429	0.018	No relevant relationship
Velocity	Depth	0.515	0.004	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Velocity	-0.324	0.081	No relevant relationship
Building Collapse 2	NZ	0.679	0.000	No relevant relationship
Building Collapse 3	Building Collapse 2	0.326	0.078	Covariance
Evacuation (after)	Depth	0.324	0.106	
Evacuation (general)	Evacuation (after)	0.616	0.001	Covariance
Evacuation (general)	Evacuation (before)	0.694	0.000	Covariance
Flood duration	NZ	0.414	0.023	No relevant relationship
Flood duration	Velocity	-0.374	0.042	Although not really that strong or interesting a relationship the correlation here again relating to different flood characteristics. The relationship is suggesting that longer lasting floods typically have lower velocities. Although there is some variation, typically the velocity is higher with quick-onset and high velocity flooding, than floods with slower onsets which typically have slower velocities.
Flood duration	Evacuation (before)	0.372	0.047	This is a relatively weak correlation and although makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood duration	Evacuation (general)	0.392	0.048	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.
Actual speed of onset	Nz	0.711	0.000	No relevant relationship
Actual speed of onset	Velocity	-0.446	0.013	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Building Collapse 2	0.495	0.005	No relevant relationship
Actual speed of onset	Flood duration	0.674	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	Nz	0.687	0.000	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced, it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.436	0.016	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Building Collapse 2	0.431	0.017	No relevant relationship

EUROPEAN DATA (NO TROUBKY) (contd)
N=33, Deaths =43 (17 observations with deaths; 16 observations with no deaths)

Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Time to flood warning	Flood duration	0.764	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.926	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**Nz**	**0.323**	**0.082**	**Not a very strong relationship here, but an obvious and well-documented one. As population at risk increases so do the number of deaths.**
Death	**% of population over 75**	**-0.275**	**0.142**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**

EUROPEAN DATA (NO CZECH)
N=33, Deaths =40 (15 observations with deaths; 16 observations with no deaths)

Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.499	0.004	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Velocity	-0.398	0.027	No relevant relationship
Building Collapse 3	Building Collapse 2	0.962	0.000	Covariance
Evacuation (general)	Evacuation (after)	0.612	0.001	Covariance
Evacuation (general)	Evacuation (before)	0.718	0.000	Covariance
Flood duration	Evacuation (before)	0.641	0.000	This is a relatively weak correlation and although makes some intuitive sense that if it is expected that flooding will last a long time then people will evacuate prior to the flooding, one might expect there also to be a relationship with evacuation after the event and flood duration. It might also be more indicative of the type of flooding. Longer duration flooding tends to occur much more slowly and provides more time for both warning and organisation. Therefore, it might be expected that floods with a longer duration an evacuation effort before the event can be organised and carried out more effectively.
Flood duration	Evacuation (general)	0.482	0.013	It is sensible to argue that more people will be evacuated from floods that last longer as they may have a more disruptive impact. Though there is again some difficulty as only official evacuation has been considered. A longer flood will also mean that there is potentially more time for people to evacuate and for the authorities to become organised.

EUROPEAN DATA (NO CZECH) Contd **N=33, Deaths =40 (15 observations with deaths; 16 observations with no deaths)**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Actual speed of onset	Building Collapse 2	0.328	0.072	No relevant relationship
Actual speed of onset	Building Collapse 3	0.348	0.055	No relevant relationship
Time to flood warning	Building Collapse 2	0.886	0.000	No relevant relationship
Time to flood warning	Building Collapse 3	0.831	0.000	No relevant relationship
Time to flood warning	Flood duration	0.388	0.031	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Death	**NZ**	**0.538**	**0.002**	**An obvious and well-documented relationship. That as population at risk increases so do the number of deaths.**
Death	**Depth**	**0.353**	**0.051**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**
Death	**% of population over 75**	**-0.275**	**0.135**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**
Death	**Flood duration**	**-0.257**	**0.163**	**This correlation is indicating that there is a negative (although quite weak) relationship between the numbers of people who are killed and the duration of the flood. This is indicating that shorter floods have more deaths. It is important to note at this stage that the slow onset floods with very deep waters have been omitted from this analysis and therefore this might be suggesting that people are more likely to be killed in floods with a flasher regime.**

JUST DEATHS (ALL DATA) Contd. **N=24, Deaths =92**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.776	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of population over 75	Depth	-0.457	0.049	No relevant relationship
Building Collapse 2	Velocity	-0.376	0.085	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the numbers of buildings that collapse decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 3	Building Collapse 2	0.374	0.086	Covariance
Evacuation (before)	% of population over 75	0.775	0.000	A very strong and interesting relationship. This correlation is indicating that areas that have a higher percentage of the population over 75 have a higher incidence of people being evacuated prior to the flooding. Although the correlations do not imply any causation, it would be sensible that any official evacuation would focus on the more vulnerable members of society and those who might not be able to evacuate on their own.
Evacuation (general)	Evacuation (after)	0.941	0.000	Covariance
Flood duration	NZ	0.583	0.004	No relevant relationship
Actual speed of onset	NZ	0.717	0.000	No relevant relationship
Actual speed of onset	Velocity	-0.382	0.087	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Flood duration	0.897	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	NZ	0.709	0.000	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced, it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.422	0.057	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Flood duration	0.953	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.945	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**% of population over 75**	**-0.424**	**0.071**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**
Death	**Building Collapse 3**	**0.929**	**0.000**	**This is a very significant relationship that as the instances of building collapse increase so do the number of deaths. In this instance the relationship is related to the ratio between building collapse and population size. It appears however that this result is being affected by the cases of Lynmouth where the population was 100 and where 39 buildings collapsed.**

JUST DEATHS (ALL DATA WITHOUT LYNMOUTH 1 AND TROUBKY)
N=22, Deaths =55

Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.775	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of population over 75	Depth	-0.501	0.034	No relevant relationship
Building Collapse 2	NZ	0.698	0.001	No relevant relationship
Building Collapse 3	Building Collapse 2	0.659	0.002	Covariance
Evacuation (before)	% of population over 75	0.774	0.000	A very strong and interesting relationship. This correlation is indicating that areas that have a higher percentage of the population over 75 have a higher incidence of people being evacuated prior to the flooding. Although the correlations do not imply any causation, it would be sensible that any official evacuation would focus on the more vulnerable members of society and those who might not be able to evacuate on their own.
Evacuation (general)	Evacuation (after)	0.924	0.000	Covariance
Flood duration	NZ	0.585	0.007	No relevant relationship
Actual speed of onset	NZ	0.713	0.001	No relevant relationship
Actual speed of onset	Velocity	-0.437	0.062	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Building Collapse 2	0.490	0.033	No relevant relationship
Actual speed of onset	Duration	0.910	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	NZ	0.709	0.001	No relevant relationship
Time to flood warning	Velocity	-0.442	0.058	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Building Collapse 2	0.297	0.092	No relevant relationship
Time to flood warning	Flood duration	0.956	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.950	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**Depth**	**0.410**	**0.058**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship.**
Death	**Velocity**	**0.507**	**0.016**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**
Death	**% of population over 75**	**-0.419**	**0.084**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**

JUST DEATHS (ALL DATA WITHOUT LYNMOUTH 1 OR CZECH)
N=22, Deaths =55

Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.838	0.000	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of population over 75	Depth	-0.540	0.031	No relevant relationship
% of population over 75	Velocity	-0.469	0.067	No relevant relationship
Building Collapse 3	Building Collapse 2	0.710	0.001	Covariance
Evacuation (before)	% of population over 75	0.770	0.001	A very strong and interesting relationship. This correlation is indicating that areas that have a higher percentage of the population over 75 have a higher incidence of people being evacuated prior to the flooding. Although the correlations do not imply any causation, it would be sensible that any official evacuation would focus on the more vulnerable members of society and those who might not be able to evacuate on their own.
Evacuation (general)	Evacuation (after)	0.920	0.000	Covariance
Population with language constraints	Building Collapse 3	0.540	0.046	No relevant relationship
Time to flood warning	Flood duration	0.508	0.038	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Death	**NZ**	**0.497**	**0.026**	**An obvious and well-documented relationship. That as population at risk increases so do the number of deaths.**
Death	**Depth**	**0.433**	**0.057**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected .**
Death	**Velocity**	**0.487**	**0.029**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**
Death	**% of population over 75**	**-0.460**	**0.073**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**

JUST DEATHS (ALL EUROPEAN) **N=18, Deaths =52**				
Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Depth	0.723	0.001	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of population over 75	Depth	-0.498	0.036	No relevant relationship
Building Collapse 2	Velocity	-0.445	0.064	A relationship might be expected between velocity and building collapse, however here this relationship appears to be negative (i.e. as the velocity increases the numbers of buildings that collapse decreases). This is potentially because the relationship is being skewed by a couple of particular events (Lynmouth 1 and Troubky). In particular the high number of buildings that collapsed in Troubky with a relatively low velocity. This was more a function of the poor construction of buildings than of the flood characteristics. NB. Once Troubky is removed from the sample there is no longer a statistically significant relationship.
Building Collapse 3	Building Collapse 2	0.862	0.000	Covariance
Evacuation (after)	Building Collapse 3	0.470	0.077	This correlation indicates basically that more people are evacuated from an area after the event where there is a higher ration between building collapse and population at risk. See above for explanation.
Evacuation (general)	Evacuation (after)	0.939	0.000	Covariance
Flood duration	NZ	0.568	0.014	No relevant relationship
Actual speed of onset	NZ	0.707	0.001	No relevant relationship
Actual speed of onset	Velocity	-0.432	0.074	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Flood duration	0.894	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	NZ	0.701	0.001	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced, it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.467	0.051	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Flood duration	0.954	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.944	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**% of population over 75**	**-0.431**	**0.074**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**
Death	**Building Collapse 2**	**0.460**	**0.054**	**An obvious and very interesting relationship that more deaths occur when there are more building collapses.**
Death	**Building Collapse 3**	**0.564**	**0.015**	**Again the same relationship as above. Although it is more statistically significant.**

JUST DEATHS (ALL EUROPEAN; NO TROUBKY)
N=17, Deaths =43

Variable 1	*Variable 2*	*Correlation Coefficient*	*P-value*	*Relationship*
Velocity	Nz	-0.440	0.077	No relevant relationship
Velocity	Depth	0.706	0.002	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of population over 75	Depth	-0.551	0.002	No relevant relationship
Building Collapse 2	NZ	0.694	0.002	No relevant relationship
Building Collapse 3	Building Collapse 2	0.657	0.004	Covariance
Evacuation (before)	% of population over 75	0.773	0.000	A very strong and interesting relationship. This correlation is indicating that areas that have a higher percentage of the population over 75 also have more people being evacuated prior to the flooding. Although the correlations do not imply any causation, it would be sensible that any official evacuation would focus on the more vulnerable members of society and those who might not be able to self-evacuate.
Evacuation (general)	Evacuation (after)	0.923	0.000	Covariance
Flood duration	NZ	0.576	0.016	No relevant relationship
Actual speed of onset	NZ	0.705	0.002	No relevant relationship
Actual speed of onset	Velocity	-0.494	0.044	Again typical of different flooding types. This relationship is suggesting that those floods that have a quicker speed of onset (e.g. a smaller time in minutes) also have faster velocities.
Actual speed of onset	Building Collapse 2	0.484	0.049	No relevant relationship
Actual speed of onset	Flood duration	0.908	0.000	Typical characteristics of flooding types. This relationship indicated that those floods with a slower speed of onset have a longer duration.
Time to flood warning	NZ	0.703	0.002	A tenuous relationship. It might be argued that those areas with higher populations at risk should be issuing warnings earlier (particularly in those situations where warning is done by individuals in the localities) as they will need to get access to the people. In reality because of the type of flooding experienced, it would be doubtful whether this is a factor in this case
Time to flood warning	Velocity	-0.492	0.045	This is indicating that those events that have a short amount of time between flood warning and the flood occurring are expected with those floods with a higher velocity. This may again be indicative of rapid onset floods where there is little time for warning.
Time to flood warning	Flood duration	0.956	0.000	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Time to flood warning	Actual speed of onset	0.949	0.000	This again is due to the type of flooding. Not only will a slow onset flood allow more time to issue a warning, as this relationship is indicating, but also there is time to refine and update the flood warning thereby allowing a more useful product.
Death	**Depth**	**0.479**	**0.052**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship.**
Death	**Velocity**	**0.551**	**0.022**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship – although it might have been assumed that this would be stronger.**
Death	**% of population over 75**	**-0.425**	**0.089**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**

JUST DEATHS (EUROPEAN, WITHOUT CZECH) **N=15, Deaths =40**				
Variable 1	**Variable 2**	**Correlation Coefficient**	**P-value**	**Relationship**
Velocity	Depth	0.765	0.001	This relationship is indicative of the type of flooding that is mainly being observed which is medium to rapid onset. That is as the severity of the flooding increases so does the flood depth and velocity.
% of long term ill	Velocity	-0.476	0.073	No relevant relationship
% of population over 75	Depth	-0.604	0.017	No relevant relationship
% of population over 75	Velocity	-0.553	0.032	No relevant relationship
Building Collapse 3	Building Collapse 2	0.691	0.004	Covariance
Evacuation (before)	% of population over 75	0.769	0.001	A very strong and interesting relationship. This correlation is indicating that areas that have a higher percentage of the population over 75 have a higher incidence of people being evacuated prior to the flooding. Although the correlations do not imply any causation, it would be sensible that any official evacuation would focus on the more vulnerable members of society and those who might not be able to evacuate on their own.
Evacuation (general)	Evacuation (after)	0.921	0.000	Covariance
Population with language constraints	Building Collapse 3	0.528	0.095	No relevant relationship
Time to flood warning	Flood duration	0.464	0.081	Again not necessarily that interesting a relationship, but it may yet again link to the different types of flooding. Those floods with a longer duration tend to be slower onset floods and are often more predictable. Therefore, not only is there the potential to warn earlier and more accurately, there will also be more lead time before the flooding occurs due to the nature of the flooding itself.
Death	**NZ**	**0.509**	**0.052**	**An obvious and well-documented relationship. That as population at risk increases so do the number of deaths.**
Death	**Depth**	**0.494**	**0.061**	**As the depth of the flood waters increase so do the numbers of deaths. This is a clear and expected relationship.**
Death	**Velocity**	**0.548**	**0.035**	**As expected there is a clear positive relationship between velocity and fatalities. i.e. the higher the velocity of the flood the lower the more people who are killed.**
Death	**% of population over 75**	**-0.470**	**0.077**	**An interesting result as it goes against some established thinking. This correlation coefficient is indicating that there is a negative relationship between the numbers of people who are killed and the percentage of the population who are over 75 years of age i.e. the more people that are over 75 the few numbers of people who are killed.** **This is counter to what others (such as HR Wallingford, 2005a) have been arguing in that those over the age of 75 are more vulnerable to flood events. What might be being seen here is that many people who are being killed are those who venture out of their homes during times of flood either to try to escape the flood waters or to save others, pets or property. Those over the age of 75 may be more aware of their limitations and therefore more likely to remain indoors. In some instances (e.g. those events where structural damage and building collapse are not relevant) this may be safer.**