1 Introduction

1.1 Background and problem definition

Recent worldwide flood events, such as Hurricane Sandy in the US in 2012, or Germany’s river floods in 2013, as well as those of the UK in 2014, demonstrate that extreme floods create huge impacts on societies. In the last decades, flood risk and damage throughout Europe has increased, mainly being attributed to development of urban areas in flood-prone regions (Barredo, 2009; Munich RE, 2010). In recent literature, flood risk is defined as the probability of flooding multiplied by the potential damage or consequences, such as economic damage or loss of life (Maaskant et al., 2009; Merz et al., 2010).

Flood damage is projected to increase even more in many areas as a result of continued urban development (Aerts et al., 2006; Bouwer et al., 2006; IPCC, 2007; te Linde et al., 2010; Ward et al., 2012). In addition, climate change may increase peak river discharges and their probabilities in many regions, causing sea level rise, which requires the implementation of strategies to manage current and future flood risks (IPCC, 2012).

This thesis focuses on flood risk management in France, where similar trends in flood risk have been observed over the last 20 years. These trends can primarily be ascribed to the urbanization of low-lying flood zones, while climate change may further increase flood risk in the future (e.g. Grésillon et al., 2008). To manage current and future flood risk in France, different adaptation strategies are available. These strategies are targeted to either reduce the probability of flooding or the potential damage. Such strategies include the installation of technical measures to reduce the probability of flooding by the provision of flood protection, such as storm surge barriers and dikes (Vis et al., 2003; Aerts and Droogers, 2004; Merz et al., 2010); the use of insurance to provide compensation, to help recovery, and to provide incentives for damage mitigation (Kunreuther, 2006; Crichton, 2008; Paudel et al., 2012); the application of spatial zoning with increased control over land-use changes and developments of new and existing urban areas (Burby et al., 2000); and, the implementation of damage reduction measures on houses regulated through building codes, also called "mitigation measures" or flood-proofing measures (Kreibich et al., 2005; Kreibich and Thieken, 2009). Recent studies have shown that an
Figure 1-1 Flood zones in France. On the left: Contours of the vulnerable zones related to rivers in 2013. On the right: Percentage of the population per town and village living in the flood zone. Source: MEDDE Cartorisque (2015).
adequate implementation of such measures can decrease the costs of floods (ICPR, 2002; Kreibich and Thieken, 2009; Kreibich et al., 2011, 2012; Bubeck et al., 2012b). However, knowledge remains scarce about the implementation and effectiveness of these flood damage mitigation measures.

### 1.1.1 Flood risk in France

Figure 1-1 shows the flood zones in France. Including the Overseas Departments and Territories (DOM-TOM), as of 2009 France had 36,679 communities (INSEE, 2009). Of these communities, almost 82% suffered from natural disasters for the years 1982-2001, and 66% experienced a flood. In the metropolitan part of the country, 17,064 communities (46% of communities), including 300 large cities, are highly vulnerable to floods; and 8% of the population (approximately 5 million people), could potentially be affected by flooding (Létrémy and Grislain, 2009). As an example, an assessment of the potential damage of a 1/100 year flood of the Seine in Paris would amount to 12-15 billion euros. Furthermore, the most damaging floods of the past years occurred in the years 2002 (departments of Gard, Hérault, and Vaucluse) and 2003 (departments of Gard and Vaucluse in the South). These floods caused, respectively, 1.2 and 1.5 billion euros of damage, as well as 24 and 7 deaths (Huet et al., 2003; Laroche, 2008). Not all of the damaged property was insured; in 2002 and 2003, only 780 million and 900 million euros were compensated, respectively.

Figure 1-2 presents the aggregated flood and storm damage in millions of euros and the number of flood and storm occurrences per decade in France since the 1950s. Classes 2, 3, and 4 are, respectively, floods or storms which caused 1-10 deaths or 5-50 million euros of damage; 10-99 deaths or 50-500 million euros of damage; and, >100 deaths or >500 million euros of damage. The frequency of floods and storms has risen since the 1980s, particularly class 3 floods. This increase is mainly attributed to higher exposure due to the construction of new buildings in flood-prone areas (Mitigation, 2005).
Figure 1-2 Number of floods of classes 2, 3, and 4 in France, per decade. A flood is defined as class 2 if it caused 1 - 9 deaths or 5 - 50 million euros of material damage. A class 3 flood caused 10 - 99 deaths or 50 - 500 million euros of damage. A class 4 flood caused more than 100 deaths or over 500 million euros of material damage. Source: EM-DAT (2015).

1.1.2 Research themes

Given the increasing flood risk in France, this thesis aims to examine the French flood risk management system, and to contribute to four research themes.

First, since 1982, properties in France have been covered for natural disasters through a natural disaster insurance coverage – the CatNat system (“Catastrophes Naturelles,” “CatNat”) – which is compulsory, and so is included in home insurance contracts. The CatNat system is regulated on the basis of the principle of national solidarity, which in practice means that the coverage is provided through a national reserve that is financed by fixed insurance premiums (Schwarze and Wagner, 2004; Van den Bergh and Faure, 2006). This enables a high market penetration rate and a large financial reserve at a low cost for policyholders (Van den Bergh and Faure, 2006). This coverage has been linked to what are called “Risk Prevention Plans,” or “Plans de Prévention des Risques” (PPRs) in French (see Figure 1-3), which aim to limit new construction and enforce the implementation of prevention measures on communities and households in flood-prone areas. However, various studies on this subject have concluded that policyholders have insufficient incentives to implement flood damage mitigation measures; therefore, calls have been made to improve the CatNat...
system in order to strengthen such incentives (Van den Bergh and Faure, 2006; Ledoux, 2009; Grislain-Létrémy and Peinturier, 2012).

Second, emerging literature exists concerning the influential factors on households’ flood damage mitigation behavior, such as individual risk perceptions or coping appraisals (Grothmann and Reusswig, 2006; Bubeck et al., 2012a). In addition, several studies have highlighted flood experience as a dominant factor of influence on flood preparedness, which implies that many people prepare after, instead of before, a flood (Siegrist and Gutscher, 2008; Kreibich and Thieken, 2009; Bubeck et al., 2013). An improved understanding of household decision-making about investments in flood damage mitigation measures are of interest, as it has been shown that many households insufficiently prepare for flooding (Kunreuther et al., 2011). Recent research suggests that it would be useful to further study household perceptions and behavior across different regions, for flood preparedness may differ with respect to the local characteristics of flooding (Bubeck et al., 2012b; Kellens et al., 2012).

Figure 1-3 Communities exposed to floods and Risk Prevention Plans (PPRs) in 2013. Source: MEDDE Cartorisque (2015).
Third, only a few studies, based on data from past floods, have shown that adequate undertaking of flood-proofing measures can considerably decrease the costs of flood damages for households. These studies estimated avoided costs, flood risk reduction, and cost-benefit ratios of investments in flood-proofing (Wind et al., 1999; ICPR, 2002; ABI, 2003; Kreibich et al., 2005; Thurston et al., 2008; Kreibich and Thieken, 2009; Kreibich et al., 2011, 2012; Aerts et al., 2014). Nevertheless, there is still little insight into how semi-structural (i.e. mitigation measures) and non-structural measures (i.e. spatial zoning) can decrease the flood risk beyond the local level, now and in the future.

Fourth, estimates of the effectiveness of flood damage mitigation measures at the local level have been obtained by simulating flood risk reduction through flood risk assessment models (e.g. Dawson et al., 2011; Poussin et al., 2012a), using expert judgment (ICPR, 2002; ABI, 2003; Defra, 2008), and empirical studies conducted after flood events on avoided flood damage (Kreibich et al., 2005; Kreibich and Thieken, 2009). The few empirical analyses of flood damage avoided by private mitigation measures discovered that such savings can be considerable (Wind et al., 1999; Kreibich et al., 2005, 2011, 2012; Olfert and Schanze, 2008; Kreibich and Thieken, 2009; Bubeck et al., 2012b). Although the studies provide useful insights into the potential damage savings from flood damage mitigation measures, it is evident that this empirical literature is scarce and focused on only a few river basins, which are located in a few countries (mainly Germany). Moreover, only a few studies examined the cost-effectiveness of these measures. Kreibich et al. (2011, 2012) estimated benefit-cost (B/C) ratios of adapting buildings to floods in Germany, which depend on the type of measures and homes, as well as on the probability of flooding. The B/C ratios are calculated using values of flood loss reductions that are based on a comparison of the means of flood damage suffered between groups of households who have, and who have not, taken flood damage mitigation measures. Applying regression analysis may be more suitable for estimating the independent effect of damage mitigation measures by controlling for other effects on flood damage, such as flood water heights (Wooldridge, 2003). Further empirical research is needed on the (cost-) effectiveness of individual flood damage mitigation measures. Such information is imperative for policymakers whom are involved in the design of flood risk management policies, for insurance companies whom are interested in reducing the flood vulnerability of their policyholders, and for households and businesses whom want to reduce the flood risk to their property (e.g. Kull et al., 2013).
1.2 Protection Motivation Theory (PMT)

For providing improved insight into households’ flood damage mitigation behavior, an extended version of the Protection Motivation Theory (PMT) has been applied in this thesis. This theory explains households’ decisions to prepare for risk using threat and coping appraisals, among other factors. PMT was originally formulated, and later revised, by Rogers (1975, 1983) to explain how individuals protect themselves against health risk. It has been applied by Grothmann and Reusswig (2006), Zaalberg et al. (2009), and Bubeck et al. (2013) in the context of flood risk. PMT predicts that individuals will protect themselves against a particular hazard if they believe that the threat of the impending hazard (“threat appraisal”) is high, and if coping appraisals are high. The latter is the case if individuals perceive that the available protective measures are effective (high “response-efficacy”), easy (high “self-efficacy”), and not too costly (low “response costs”) to implement. The extended version applied in this thesis includes five additional components as shown in Figure 3-1 that have been extracted from a literature review of factors of influence on flood preparedness: flood experience, risk attitudes, flood risk management policies, social networks and social norms, and socioeconomic factors (see Chapter 3).

1.3 Research questions

The four themes listed in Section 1.1 are examined in this thesis according to the two main research objectives to (a) improve understanding of the implementation of flood damage mitigation measures by households in France and the factors that influence individual decisions to prepare for flooding, and (b) obtain insights into the (cost-) effectiveness of flood damage mitigation measures in reducing flood losses. Research questions 1 and 2 provide answers for objective 1, and research questions 3 and 4 provide answers for objective 2.

This thesis will analyze the following research questions:

1. How does the French CatNat system influence households to implement flood damage mitigation measures, and what can be done to improve the incentives with regard to risk reduction?

2. What factors explain household decisions as to whether to prepare for flooding? In particular, to what extent does PMT explain households’ flood preparedness decisions, and what important elements need to be added to that theory?
3. What methodology can be developed to assess the effectiveness of spatial zoning and flood damage mitigation measures in reducing current and future flood damage and risk in the Meuse river basin?

4. How to assess the cost-effectiveness of individual mitigation measures to reduce flood risk for homeowners? What measures should be prioritized that homeowners can implement for reducing flood risk to their properties?

1.4 Data and methods

1.4.1 Survey data and statistical analysis

In order to answer questions 1, 2, and 4, a mail survey was conducted, which was targeted at inhabitants of three flood-prone regions in France: namely the Ardennes, the Var, and the West coast. Table 1-1 shows that these areas differ with respect to flood history, flood types, and local flood management approaches and regulations. These three areas were chosen because of the past experiences with floods. The Ardennes are regularly affected by floods from the Meuse and its tributaries (“historical” floods in 1910, 1926, 1947, 1983, 1984, 1993, 1995, 2001; “smaller” floods in 1920, 1955, 1999, 2003) (Epama, 2011). In particular, the 1993 and 1995 floods caused one death in 1993, and respectively caused about €120 million and €240 million of damage (EPTB, 2011).

The second area is the Var, along the rivers Argens and Nartuby which flooded in June 2010, and again in June and November 2011 by smaller floods. The 2010 flood was a flash flood. It was declared by Meteo France to be the worst flood since 1827 (France Soir, 2010). It caused more than €600 million of insured flood damage and 23 deaths (FFSA, 2011). The respondents were sampled in the villages along the rivers based on the very few existing PPRs and on data collected by the author during a field trip to site in March 2011.

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The third area is in the West of France, in Charente-Maritime and two villages in Vendee. This area was flooded in the end of February 2010 as a consequence of the storm Xynthia. The damage was caused by the combination of the high tide with the storm and badly maintained dikes. This event caused €1.5 billion of damage, with 700 million Euros for the floods, and 53 deaths (Anziani, 2010). The individuals in the sample were selected using the pre-PPRs maps realized after the flood which show, at the street level, which parts of which villages were flooded. One exception in Charente-Maritime, is the village of Charron in which all the flooded inhabitants of the village (including the ones who moved after the flood) were contacted using the contact details provided by the president of the association created after the flood5.

The survey was conducted in villages and towns that were carefully selected on the basis of having experienced a flood event(s) in the past. The survey included a range of questions about flooding experiences, individual flood risk perceptions, coping appraisals, and other factors of influence on flood preparedness, implemented flood risk mitigation measures, and socioeconomic characteristics (see Chapters 2, 3, 5, and Appendix C).

The questionnaires were pre-tested with 10 face-to-face interviews and a mail pilot that was organized by the survey research company IPSOS. For this pilot, 200 letters were sent to the same areas as the sample areas of the final survey, with 26 completed questionnaires being returned. Observations obtained with the pre-tests were excluded from the final survey. The final survey was sent by postal mail to 8,201 households, which were equally divided over the three regions. Sent specifically, were 255 letters to the previous and current inhabitants of Charron, which is a village that had 884 households on the West coast in 2009, in which 196 houses have been demolished by the state after the 2010 flood (Batirama, 2012; INSEE, 2013). It was explicitly asked to the respondents from Charron who were flooded, to list the flood mitigation measures that were implemented in the home that was flooded (i.e. their previous home, if they had since moved). All the other respondents were asked for the mitigation measures that were implemented in their current residence. Approximately 10.8 per cent, or 885 respondents, returned the survey, including 59 households from Charron. Of the respondents, 530 had been previously flooded.

Regression models were used to offer insights into both the individual flood preparedness decisions and the (cost-) effectiveness of flood damage mitigation measures. The effects of several variables that potentially influence mitigation behavior and the

5. Reconstruire Charron: reconstruirecharron.viabloga.com
level of flood damage are estimated using ordinary least squares (OLS) regression models, utilizing the statistical software SPSS 20.

Table 1-1 Characteristics of extreme flood events over the last 25 years in the three study regions that are included in the sample of the survey.

<table>
<thead>
<tr>
<th>Types of floods</th>
<th>Ardenes (river Meuse)</th>
<th>Var (rivers Argens/ Nartuby)</th>
<th>West (Atlantic coast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrem flood events</td>
<td>Slowly rising river floods</td>
<td>Flash floods</td>
<td>Coastal floods</td>
</tr>
<tr>
<td></td>
<td>1995: €240 million³</td>
<td></td>
<td>€700 million⁴</td>
</tr>
<tr>
<td># Casualties</td>
<td>1993: 1 death⁵</td>
<td>June 2010: 25 deaths⁴</td>
<td>47 deaths⁴</td>
</tr>
<tr>
<td>Existing Risk prevention plans (PPRs)</td>
<td>In every village and town since the 1995 flood</td>
<td>Only very few PPRs are in place</td>
<td>Most villages did not have PPRs before 2010</td>
</tr>
</tbody>
</table>

⁴ Epama, 2011; ⁵ labelled “worst flood since 1827”, France Soir, 2010; ⁶ EPTB, 2011; ⁷ FFSA, 2011; ⁸ Anziani, 2010

1.4.2 Flood damage model

In order to answer question 3, a flood damage model was developed to assess the sensitivity of riverine flood risk to both changes in land use and climate. Based on the current and future risk simulations, the potential of different adaptation strategies for flood risk reduction was assessed at the regional scale. The study was carried out for a case study region in the Meuse river basin.

The river Meuse is a predominantly rain-fed river, with a length of approximately 875 km from its source in France, to its mouth in the Netherlands. Its catchment area extends over parts of Belgium, France, Germany, Luxembourg, and the Netherlands—an area of approximately 33,000 km². The Meuse basin is one of the most densely-populated areas of Western Europe, being inhabited by an estimated 9 million people (De Wit et al., 2007). With a relatively rapid response to rainfall, the Meuse is sensitive to floods (Van Pelt et al., 2009), with peak floods mainly occurring during the winter. The section of the Meuse studied in this research flows from its source in France, near the village of Pouilly-en-Bassigny (municipality of Le Châtelet-sur-Meuse), through Belgium and the province of Limburg, to near the village of Mook in the Netherlands.

The modeling study estimated flood inundation and extent, flood damage, and flood risk using simulated damage results for multiple flood return periods in order to calculate the risk, or “expected annual damage” (EAD). The EAD was estimated by
combining the damage results for different exceedance probabilities, and integrating the area under an exceedance probability loss curve (i.e. risk curve) (Grossi and Kunreuther, 2005). A inundation model, called the Floodscanner model (Ward et al., 2011), was coupled with a damage model, called the Damagescanner model (Klijn et al., 2007; Aerts et al., 2008), to simulate damage and flood risk for the current situation, and for future scenarios of land-use and climate change, with and without adaptation strategies at the regional scale.

The adaptation strategies included spatial zoning measures and three types of flood-proofing measures: namely, dry-proofing, wet-proofing, and a combination of dry- and wet-proofing. The damage- and risk-reduction capacity of the adaptation strategies was assessed by using relative changes, as research shows that estimates of relative changes in flood damage are more robust than estimates of absolute changes (Bubeck et al., 2011). These strategies were combined with land-use maps for the years 2000 and 2030, which were used to represent the respective exposure. The hazard was represented by inundation maps for nine different return periods, for climate in the year 2000, and for a future climate in the year 2030. Stage-damage functions represent the vulnerability by providing a relationship between inundation height, land use, and damage. To assess the potential impact of spatial zoning measures, the 2030 land-use maps were modified according to a spatial zoning project conducted in the case study area. To assess the impact of the mitigation measures in residential areas, factors that represented reduced flood damage due to mitigation were applied to the stage-damage functions.

1.5 Outline of the thesis

The remainder of this thesis consists of four chapters that are based on articles published in international, peer-reviewed scientific journals, and a final conclusion chapter (Figure 1-4). Chapter 2 introduces the French CatNat insurance system, and assesses its effectiveness in stimulating the undertaking of flood damage mitigation measures by households (research question 1). The same chapter also describes in detail the survey that was conducted in three flood-prone regions of France in 2011. Chapter 3 introduces the extended PMT, and provides the results of the analysis of the survey with regards to the factors influencing the implementation of mitigation measures (research question 2). In Chapter 4, adaptation strategies are integrated into a flood damage model to evaluate the influence of these strategies on the current and future flood damage and risk for the river Meuse (research question 3). Using the collected survey data, Chapter 5 presents the results of the potential flood damage that can be avoided by specific flood damage mitigation measures, and evaluates the
(cost-) effectiveness of these measures (research question 4). Chapter 6 provides a conclusion.

Figure 1-4 Outline of the thesis.
2 Stimulating flood damage mitigation through insurance: an assessment of the French CatNat system

Abstract

Flood risk has increased in France in the last 20 years and is projected to increase further in the future due to climate change and increase in exposure. Since 1982 France has a natural disasters insurance system (‘CatNat’) in place that covers flood damage. This insurance system has been combined with what are called “Risk Prevention Plans” (PPRs) in order to stimulate the undertaking of flood risk mitigation measures by communities and households. However, these schemes do not provide optimal incentives for flood damage reduction. This is confirmed by the results from a survey about flood preparedness of 885 households who live in flood-prone areas in France, which are presented in this chapter. Moreover, this chapter provides suggestions for improvement, which are assessed on their potential economical, social and political implications. Among these suggestions are increasing the effectiveness of PPRs and increasing the incentives to apply and implement PPRs; improving the monitoring of the implementation of damage mitigation measures; and the possibility to differentiate premiums and deductibles according to flood risk.

2.1 Introduction

Flood damage has increased in France over the last 20 years and can be expected to increase in the future as a result of socio-economic developments such as the urbanization of vulnerable locations. In addition, climate change may increase flood risk in certain regions while it may lower risk in others (Grésillon et al., 2008). To manage future flood risk, several flood adaptation measures can be implemented, which can roughly be divided into measures that reduce the probability of floods and measures that limit flood damage (Botzen and Van den Bergh, 2009). Damage reduction measures can be implemented in flood-prone areas at the household level, or at the community level through, for example, flood zoning and building codes. Damage reduction measures at the household scale, which are referred to as “mitigation measures”, are receiving increased attention, particularly in combination with flood insurance schemes (Kunreuther, 2006; Botzen et al., 2009b). It has been shown that these measures can considerably decrease flood risk if they are adequately implemented (ICPR, 2002; Kreibich and Thieken, 2009; Kreibich et al., 2011, 2012).

Since 1982, France has had a natural disaster insurance system (“Catastrophes Naturelles”, “CatNat”). The CatNat system is regulated on the basis of the principle of national solidarity, which in practice means that the compulsory natural disaster coverage is provided through a national reserve that is financed by fixed insurance premiums (Schwarze and Wagner, 2004; Van den Bergh and Faure, 2006). This enables a high market penetration rate and a large financial reserve at a low cost for policyholders (Van den Bergh and Faure, 2006). The natural disaster coverage has been linked to what are called “Risk Prevention Plans”, or “Plans de Prévention des Risques” (PPRs) in French, which aim at limiting new construction and enforcing the implementation of prevention measures by communities and households in flood-prone areas. However, various studies on the subject have concluded that policyholders have insufficient incentives to implement flood damage mitigation measures, and, therefore, calls have been made to improve the CatNat system in order to strengthen such incentives (Van den Bergh and Faure, 2006; Ledoux, 2009; Grislain-Letrémy and Peinturier, 2012).

This chapter assesses the functioning of the French CatNat system (Section 2.2) and its results in stimulating the undertaking of flood damage mitigation measures by households (Section 2.3). For this purpose, a survey was conducted among 885 households in three flood-prone regions of France in order to examine current levels of flood preparedness (Section 2.4). Moreover, suggestions for improvement of the CatNat system are discussed (Section 2.5).
2.2 The French natural disaster insurance: the CatNat system

In France, insurance that covers damage to properties is provided via two arrangements: namely, insurance for events that are regarded as insurable, and a separate natural disaster protection which covers damage that is considered as non-insurable. Table 2-1 presents these two arrangements of coverage and their characteristics. A private insurance market exists that covers damage to properties caused by non-catastrophic risks. These contracts are shown in Table 2-1 as “Contracts for insurable damage”. The home insurance contracts are referred to as Multi-Risk Habitation (MRH) contracts. The premiums of the contracts depend on the probability of damage, the value of the contents of the insured buildings, the options chosen by the policyholders, and the exposure to the hazards covered by the contract. It is compulsory for tenants and, in most cases, for homeowners, to purchase an MRH contract. The penetration of the insurance for households in metropolitan France is more than 99 percent (Grislain-Letrémy and Peinturier, 2010).

In addition to the insurable damage contracts, a public-private compensation system – the CatNat system\(^6\) – exists that covers losses that cannot be insured in private markets, such as flooding. This system and the kind of disasters it covers are described under the heading “Natural disasters protection” in Table 2-1 (De Marcellis-Warin and Michel-Kerjan, 2001). Since 1982, insurers are required to extend the existing property (MRH and other contracts) and vehicle insurance contracts to cover damage caused by natural disasters (Van den Bergh and Faure, 2006). For the CatNat coverage, a natural disaster premium is added to the properties and the vehicles contract premiums. These natural disaster premiums are not differentiated according to the actual natural disaster risk, but follow the principle of national solidarity and have been fixed by the government (Van den Bergh and Faure, 2006). The premium for the natural disaster coverage is currently at 12 per cent of the MRH premium, which was on average 18 euros per household in 2007 (Bersani et al., 2010).

One of the main reinsurers providing coverage for the CatNat system in France is the Central Fund for Reinsurance\(^7\) (CCR), which is an international reinsurance company owned by the French government. The government will compensate damage above a certain amount stipulated in the law by providing an unlimited guarantee of compensation exclusively to the CCR, and not to the other reinsurers in the market (CCR, 2008). This guarantee implies that after large floods, such as damaging floods

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6. Short for “Catastrophes Naturelles” in French (Natural Catastrophes in English).
7. “Caisse Centrale de Réassurance” in French.
in Paris, the government pays for part of the compensation provided by CatNat. For such floods, the costs of this state guarantee could be in the order of several billions (Bersani et al., 2010).

Table 2-1 Characteristics of the natural disaster coverage scheme in France, specified for the contracts affected by the natural disaster law (contracts for properties and vehicles) and the added protection against natural disasters.

<table>
<thead>
<tr>
<th>Contracts for insurable damage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Insured good</td>
<td>Properties (MRH) and insured goods, other than motorised terrestrial vehicles</td>
</tr>
<tr>
<td>Coverage options</td>
<td>Legal liability; Storm, hail and snow; Fires; Theft; Glass damage; Water damage; Electrical damage.</td>
</tr>
<tr>
<td>Premiums</td>
<td>Risk-based</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural disasters protection</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard coverage</td>
<td>Floods and or mudslides; Earthquakes; Landslides; Flows of water, mud or lava; Volcanic eruptions; Geotechnical subsidence (differential landslides following droughts and rehydration of the soils); Cyclonesb; Tidal waves; Moving masses of snow or ice.</td>
</tr>
<tr>
<td>Premiums</td>
<td>+12 per cent MRH</td>
</tr>
</tbody>
</table>

Source: Adapted from Caisse Centrale de Réassurance (2008); Letrémy and Grislain (2009).

Notes:

a The contracts mentioned here are all the contracts covering damage to vehicles, apart from the fire and theft contracts.
b Only in overseas departments. Storms are never covered.

In order to be compensated by the natural disaster coverage, events should be recognised as natural disasters through natural disaster decrees ("Arrêté Catastrophe Naturelle"), signed by the government (Legifrance, 2013). Such decrees can only be obtained if the damage is predominantly inflicted by a natural cause of “abnormal scale”. The level of damage itself is not assessed when conferring the status of a nat-
ural disaster. An “abnormal scale” for flooding is usually defined as a flood event with more than a decennial return period at the regional scale, and a tricennial return period at the catchment level (Vinet, 2008). However, an assessment of the CatNat system showed that the “abnormal scale” of the disasters is insufficiently based on rigorous scientific expertise and may, therefore, vary between events (Dumas et al., 2005). Currently, a reform is being prepared which should result in a closer involvement of scientific expertise in the assessment of the intensity of an event (Projet de loi, 2012). Between 1982 and 2007, about 80 to 90 per cent of the communities that applied for a natural disaster decree after being flooded were granted a natural disaster declaration (Caisse Centrale de Réassurance, 2008).

2.3 Incentives for flood damage mitigation

2.3.1 Risk Prevention Plans (PPRs)

Risk Prevention Plans (PPRs) were created in 1995. Their general purpose is to regulate land use in order to reduce the potential exposure of property and people to natural hazards (Blanchi et al., 2003). In practice, PPRs do not provide zero risk for communities but they are meant to guide and stimulate the undertaking of risk-reducing measures by community officials and households, as well as to limit construction of new buildings in vulnerable areas. PPRs are carried out by the state and approved by a prefectoral decree (“Arrêté préfectoral”). The procedure for developing a state-recognised PPR starts with an “application decree” (“Arrêté de prescription”). The procedure from this decree to the approval of the PPR and its finalisation should take approximately three years.

A PPR for flood damage prevention and reduction in a certain region delimits the area that can be affected by the highest known historical flood or the 100 years flood, depending on which one is higher. On the basis of this information, the plan contains a map which shows those zones where it is not allowed to build and those where building is allowed under certain conditions. In the areas where construction is allowed under stipulations, the PPR can define compulsory and recommended measures that reduce exposure and vulnerability to floods and protect the population. These measures can be applicable to public authorities as well as private households. Four types of measures can be recommended or made compulsory. These measures are prevention measures, protection measures, safeguard measures, and measures for already built-up areas and existing buildings. The first three types of measures can include measures to increase the knowledge about the hazard and the
passive protection against the hazard, or reduce the populations’ vulnerability. The measures for existing buildings are meant to reduce the vulnerability of owners, users, and farmers. The costs of these measures cannot exceed 10 per cent of the value of the buildings (Prim.net, 2013). This limit may preclude the taking of potentially expensive structural flood damage mitigation measures in homes which are not very expensive, for example, in rural areas. The compulsory measures have to be implemented within five years after the approval of the PPR.

In principle, insurers have the option not to compensate flood damage or to apply discounts on the compensation if properties or activities are located in non-authorised construction zones, or if the compulsory measures have not been implemented in the requested time after the approval of the PPR. However, in these cases, an insurer must have authorisation from the Central Tarification Board\(^8\) that is created for the protection of the consumers’ interests. This derogation option can only be used by insurers when the insurance contract is first signed, or when it is renewed (BCT, 2010). In certain individual cases, insurers can also increase deductibles as a sanction for non-compliance with the prescriptions of an approved PPR.

Figure 2-1 shows the difference between the growth of urban areas in highly vulnerable (in dark grey) and non-vulnerable zones (in light grey) in communities with (on the left) and without (on the right) a PER or a PPR between 2000 and 2006, for 424 communities with more than 10,000 inhabitants that are exposed to a major risk. This graph shows that communities without PPRs have similar growth rates in vulnerable and non-vulnerable zones, while communities with PPRs have a growth rate that is 3 to 4 times higher in non-vulnerable areas than in vulnerable areas. Even though the urban growth did not completely stop in vulnerable areas of communities with PPRs, these communities undertake less urban development in vulnerable areas than communities without PPRs. These results suggest that PPRs have been effective in restraining development in vulnerable zones.

It should be noted that there is high spatial variation in developments in areas vulnerable to flooding between the departments. Research conducted at the level of the departments in which the same communities as in Figure 2-1 are located shows that about 45 per cent of these departments had the constructions in vulnerable areas mainly built in communities without PPRs, while 55 per cent had their constructions

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8. The board’s main activity is to evaluate requests for compensation by policyholders who were denied reimbursements, and thus determine whether an insurer can be forced to compensate (Legifrance, 2013).
in vulnerable areas mainly built in communities with PPRs. This seems to indicate that PPRs do not succeed in limiting new construction in vulnerable areas.

Another assessment criterion of the effectiveness of PPRs is whether the measures prescribed are implemented by communities and households, and whether these measures save damage during floods. There are examples where PPRs were effective in reducing damage, such as with the PPRs of the Valley of the Siagne (Nifle et al., 2003). These PPRs were focused on measures to increase the discharge capabilities of the river, not on housing adaptation. During the floods in 2000, these PPRs enabled the river Siagne to withstand a flow of 300 m$^3$/s without flooding the area, while before the implementation of the measures the river would flood its surroundings during a flow of 200 m$^3$/s. However, this is only one example.

A report of the General Inspection of the Environment on the 2002 flood concluded with the following two statements: the newly built houses in vulnerable zones were not built to resist floods, and the vulnerability of existing properties was insufficiently taken into account in the approved PPRs (Boulet-Desbareau et al., 2005). Additionally, Dumas et al. (2005) indicated that, even if risk prevention policies gave a high priority to the prevention of hazards affecting human lives, the current objective of prevention of property damage is not clear enough. Furthermore, it appears
that the measures prescribed are often only reminders of the existing laws and may not be adequate for local issues (Ledoux, 2009). Blanchi et al. (2003) and Vinet (2008) showed that the maps, the criteria defining the level of the hazard, and the measures of PPRs are inconsistent between departments, and that there is a lack of capacity to monitor the implementation of the mitigation measures. Dumas et al. (2005) concluded that the implementation of the construction rules described in PPRs is insufficient. Ledoux (2009) argued that PPRs may suffer from having too many objectives, which reduces their effectiveness. In addition, the prescribed measures may be improperly implemented (Letrémy and Grislain, 2009), and some communities have problems with creating adequate flood protection infrastructure because some areas near rivers and the coast that include dikes are privately owned (Savidan, 2011).

2.3.2 Deductibles' adjustment as an incentive for applying for a PPR

In France, the deductibles of natural hazards coverage are fixed by the government. For damage contracts, such as the MRH contracts, the deductibles are 380 euros for individual properties. In 2000, two governmental decrees allowed for an adjustment in the level of these deductibles based on flood risk. This adjustment is meant to give an incentive to the policyholders of the most vulnerable communities to exert pressure on their prefects and mayors to ask them to request the application of a PPR. The adjustment is based on whether a vulnerable community has applied for a PPR, and on the number of natural disaster decrees the community has been granted for the same hazard during the five years before the last disaster. The deductibles of households living in communities vulnerable to flooding without a PPR are multiplied by two, three or four times their original level if they have received, respectively, three, four, or five or more disaster decrees in the past five years for the same kind of disaster. The adjustment stops as soon as a procedure for a PPR application decree starts, so that the deductible level is back to the original amount. The adjustment will start again if the PPR has not been approved after four years.

Figure 2-2 has been constructed using the GASPAR database (2010) of the French government which contains information on natural disasters since 1982. This figure shows the percentages of communities that had an approved or applied plan of exposition to the hazards (PER) or a PPR for floods classified according to the number of times they were flooded between 1995 and 2010. PERs were replaced by PPRs in 1995. Only about 380 PERs were developed after the 1982 CatNat law, while about 12,900 PPRs were developed between 1995 and 2010. According to Figure 2-2, in 2010 about 70 per cent of the communities that were flooded five times or more
between 1995 and 2010 had applied for a PPR, while only 50 per cent had an approved PPR. This percentage is rather low given the high flood risk of these communities. The figure, moreover, shows that the percentage of communities with an applied or an approved PPR is higher for communities that have been flooded more often and, therefore, mostly benefit from mitigation measures. Nevertheless, the figure suggests that there is scope to increase the overall application of PPRs since many communities vulnerable to flooding do not have an approved PPR.

The impact of the adjustment of the deductibles on increasing the production of PPRs cannot be easily assessed. The deductibles’ adjustment policy is not linked to the approval of a PPR, but only to its application decree, and, hence, it has been argued that it has only created an “announcement effect” (Letrémy and Grislain, 2009) in which communities applied for a PPR to avoid the adjustment, but didn’t carry the work leading to the approval of the PPR.

It could be expected that the sharpest increase of PPRs applications occurs after the first and second floods since this is when flood awareness increases the most. However, it could also be expected that if the deductibles’ adjustment had an impact on PPRs application, sharp increases in the applications of PPRs would be observed in Figure 2-2 by communities that suffered more floods. None of these two results are
apparent in the figure. Figure 2-2 shows that although the percentage of communities who apply for a PPR increases when communities are flooded more often, this percentage increases with smaller steps when floods occur more frequently. An explanation for the increase in PPR applications can be that with the increase in the number of floods and flood damage, households’ flood risk awareness also increases, although this effect becomes smaller after repeated flood events. Another explanation is that the deductibles’ adjustment has an impact but either few communities are affected by the adjustment, or the adjustment provides only a small incentive to apply for a PPR. Both explanations imply that the overall effectiveness of the deductibles’ adjustment is probably minor.

The fixed and not-adjusted deductible is unlikely to provide significant incentives to reduce flood risk. As it is fixed nationally, it cannot encourage households to settle in non-vulnerable areas. In addition, the standard deductible for households is 380 euros, and is likely to be too low to influence mitigation decisions. The maximal (adjusted) deductible of a household is 1,520 euros. This amount is still small compared with the potential flood damage to a house, and might not be a sufficient incentive for households to decide to force unwilling mayors to initiate an application for a PPR.

2.3.3 The Barnier fund and other subsidies for damage mitigation

In terms of financing damage mitigation measures, since 2005 the Fund for the Prevention of Major Natural Risks, also called the “Barnier” fund, can provide subsidies up to 125 million euros per year for studies on assessments of natural disaster risk and potential prevention and protection measures for buildings. In towns with an applied or an approved PPR, the fund can finance up to 50 per cent of the costs of such studies, and, respectively, up to 40 per cent or 50 per cent of the costs of prevention works, and up to 25 per cent or 40 per cent of the costs of protection measures included in a PPR (Legifrance, 2013). An aim of this subsidy is also to finance the relocations of insured homeowners and the destruction of their houses if they are exposed to natural hazards that pose a considerable threat to human lives or were severely damaged by a natural disaster. In 2009, the Barnier fund was financed by collecting 12 percent of the natural disaster premiums (Létrémy and Grislain, 2009). Apart from this fund, it is also possible to request special discounts on taxes to pay for mitigation measures. Other funding sources are reductions or loans of the national income tax (Risques majeurs, 2013).
After studying all the subsidy possibilities offered by the government, such as the tax discounts, the loans on income taxes, and the Barnier fund, the French Account Court (Cour des comptes, 2009) reported that the financial means for PPRs and risk-reducing works are complex and confusing. Concerning the Barnier fund itself, the Account Court noted that the investments for the reduction of the vulnerability to hazards are still low, and most of the completed projects financed in 2007 were simple projects or studies. Another limitation of the fund is that it only finances measures made compulsory by an approved PPR. The funding does not depend on the flood risk and cannot be provided to communities without PPRs or with PPRs in the application stage. The expenditures of the fund have mostly increased over time. However, the balance at the end of each year decreased, which threatens the sustainability of the fund. To remedy this problem, the percentage contribution from the natural disasters premiums to the fund has been increased regularly. However, to ensure long-term financial balance it is necessary to stabilize the costs of the studies and measures subsidised by the fund, or to find alternative sources of funding.

2.4 A household survey about flood preparedness in France

2.4.1 Description of the survey

A mail survey was conducted in order to examine the level of households’ flood preparedness in flood-prone areas in France, as well as the influence of the CatNat system’s incentives on this preparedness. This survey was targeted at inhabitants of three flood-prone regions: namely, the Ardennes; the Var; and the West coast. Chapter 1 shows that these areas differ with respect to the kinds of floods they face; their flood experiences; and the existence of PPRs. The survey was conducted in villages and towns that were carefully selected on the basis of whether or not they have experienced flood events in the past. It was expected that our respondents are very well prepared for flooding, because the benefits of flood damage mitigation measures are very high for this sample.

The questionnaires were pre-tested with ten face-to-face interviews and a mail pilot that was organized by the survey research company IPSOS. For this pilot, 200 letters were sent to the same areas as the sample areas of the final survey; 26 completed
questionnaires were returned\textsuperscript{10}. The final survey was sent by postal mail to 8,201 households, which were equally divided over the 3 regions. 251 letters were sent specifically to the (previous) inhabitants of Charron, which is a village with 884 households in 2009 on the West coast in which 196 houses have been demolished by the State after the 2010 flood (Batirama, 2012; INSEE, 2013). We explicitly asked the respondents from Charron who were flooded to list the flood mitigation measures that were implemented in the home in which they were flooded (i.e. their previous home if they moved). All other respondents were asked for the mitigation measures that were implemented in their current residence. A total of 885 respondents (10.8 per cent) returned the survey, including 59 households from Charron. In total, 530 respondents have been previously flooded.

2.4.2 Implementation of structural, avoidance, and emergency preparedness measures

In order to assess the current level of flood preparedness by households, respondents were asked for 21 measures whether or not they were implemented in their home. Based on answers from an open-ended question that asked respondents whether they had implemented other measures, three measures were added to the list. The authors have classified these 24 measures in three categories: namely, structural measures, avoidance measures, and emergency preparedness measures. Structural measures modify the structure of the home. Avoidance measures limit flood damage to the contents of the home, for instance, by moving furniture. Emergency preparedness measures prepare the household to react to an imminent threat by enabling them to undertake emergency measures \textit{stricto sensu} when a flood is announced. Figure 2-3 and Figure 2-4 show the percentage of respondents who answered that a particular measure was implemented in their home. The results are shown for all of the respondents as well as for each region separately.

\textsuperscript{10} To trial the questionnaire, an open-ended question was included at the end which gave respondents the opportunity to comment on the survey and to indicate whether some questions were unclear. Following several suggestions provided during the pilot phase, the list of flood damage mitigation measures was simplified. A few measures were reorganised or split, added to, or deleted from the final list. This was done to obtain a list that corresponds to the types of measures that have actually been (or can be) implemented by households, while keeping this list as generally applicable as possible. The revisions aimed to make the questions better understandable and as much to the point as possible. In addition, IPSOS simplified the questionnaire and slightly modified its layout to give it a professional appearance.
Figure 2-3 Percentage of implementation of 14 structural measures in three flood-prone areas in France (the Ardennes, the Var, and the West). Note: W&E = walls and equipment.

Figure 2-4 Percentage of implementation of 5 avoidance and 5 emergency preparedness measures in three flood-prone areas in France (the Ardennes, the Var, and the West).
It appears from the figures that certain measures have been implemented by many respondents, while other measures have a very low implementation rate. Many respondents in all regions (78 per cent) have a water-resistant floor at the ground floor level. Other popular measures are keeping above the most likely flood level: the electrical meter (82 per cent); the power sockets of the ground floor (62 per cent) and of the cellar (58 per cent); electrical appliances like the boiler and the heater (60 per cent); and personal documents (72 per cent). The history of severe flood events in the sample areas can explain the high rate of implementation of some of these measures, such as the use of tiles on ground floors, the positioning above the most likely flood level of boilers, heaters, and power sockets, while power sockets are usually installed at the floor level in France. Some of the high implementation rates may also be related to the perceived effectiveness of certain measures to protect the household against other risks. For example, storing personal and important documents above the most likely flood level was specified by a respondent as something that she did in order to protect these documents against theft.

In contrast, other measures have a low implementation rate. Strengthening the foundations against water pressures (21 per cent), using water-resistant materials for the walls of the ground floor (22 percent) and of the cellar (27 per cent), or having a water-resistant floor in the cellar (41 per cent) are structural measures that can be costly if they are not undertaken during the initial construction or planned renovations of the house. Other structural measures, as well as avoidance and emergency preparedness measures, have low rates of adoption, although they are relatively easy and non-expensive to implement. These low rates must, therefore, have other reasons than their costs, such as a lack of knowledge about how to install the measures or about their effectiveness in reducing the impacts of floods. In particular, installing anti-backflow valves (10 per cent), installing a pump (10 per cent) or a drain around the house (23 per cent), choosing and placing furniture in the house to avoid flood damage (20 per cent), anchoring or getting rid of the oil tank (17 per cent), keeping sandbags or other water barriers in place (6 per cent), and making a family emergency plan (14 per cent) are measures which have low implementation rates. An explanation for the low percentage of respondents keeping water barriers may be that sandbags and water barriers take space for stocking, and can be perceived to hamper the appearance of the house or decrease its market value if they are installed permanently (Harries, 2008)\textsuperscript{11}.

\textsuperscript{11} Some towns or villages in the Ardennes provide sandbags and flood shields. This reduces the need for households to own this equipment.
Figure 2-3 and Figure 2-4 show that respondents from the Ardennes generally take more mitigation measures than respondents from the Var, who take more measures than the respondents from the West of France. 15 of the 24 measures have been implemented more often in the Ardennes than in the other regions. Of these 15 measures, 11 have also been more often adopted in the Var than in the West. For these measures, the difference in implementation rates between the Ardennes and the West can be as high as 26 per cent. Floods in the West are rare which can explain the relatively low level of flood preparedness there. Moreover, the type of measures adopted by households can differ between regions because of differences in local flood characteristics. For example, compared to the Ardennes, avoidance measures are less often implemented in the Var and the West where they are less effective due to high potential depth and high flow velocity of floodwaters.

Certain measures which have a low implementation rate could significantly decrease flood damage. In particular, it has been shown that waterproofing of cellars can be very cost-effective in flood-prone areas (Kreibich et al., 2011, 2012) and reduce flood damage between 10 per cent and 85 per cent depending on whether floodwaters enter the cellar (ICPR, 2002). When regularly maintained, the use of anti-backflow valves, a pump, or drains, can significantly reduce the amount of floodwaters entering the home (Boulet-Desbareau et al., 2005). Kreibich and Thieken (2009) show that flood-adapted furnishing and use of the rooms of the home can reduce flood damage of households, on average, by 46 per cent to 53 per cent. According to the ICPR (2002), changing the heating system to gas instead of oil, and anchoring, or flood-proofing the oil tank can reduce the damage to households by up to 50 per cent. Oil tanks that are not flood-proofed can contaminate floodwaters and significantly augment flood damage (Kreibich et al., 2011, 2012). Water barriers can also be very effective in reducing flood damage. The ICPR (2002) estimates that these measures can reduce flood damage by 60 per cent to 80 per cent, while damage savings can be 30 percent according to Kreibich and Thieken (2009). Family emergency plans can help prepare and protect households by anticipating and organizing their response to floods.

2.4.3 Influence of the CatNat system on households’ mitigation behaviour

The influence of the CatNat system on the mitigation behaviour of households is assessed using the answers to two questions of the survey. The first question asked respondents who had taken flood risk mitigation measures how they had paid for these measures with answer options “previous compensation from insurance”, “subsidy”, “own funds”, “did not pay the measures themselves”, and “other”. In total, 832 respondents took at least one flood preparedness measure. Of these, it appears from
the results of the survey that only 2 respondents used subsidies to pay for their measures (Section 2.3.3), and 185 respondents (22 per cent) used previous compensation from their insurer to pay for the implemented measure(s) (Section 2.2). The second question asked the respondents whether they took the measures because they had received incentives to take the measures from their town, their insurer, or from another source. Incentives from the town were stipulated to include the prescribed measures of a PPR. Incentives from the town or the insurer may, therefore, include, but are not limited to, the effect of PPRs (Section 2.3.1) and increased deductibles (Section 2.3.2), as well as information provided by the town or the insurer. Only 17 respondents (2 per cent) replied that they had received incentives from their town to implement flood damage mitigation measures, and 45 respondents (5 per cent) had received an incentive from their insurer to do so. 107 respondents (13 per cent) replied that they had received incentives from other sources, such as their family or themselves. In the Ardennes, the low rate of respondents who replied to have received incentives from their town may be related to the facts that this area is regularly flooded, PPRs have already been approved for years, and measures may have been implemented even before the approval of the PPRs. However, the data gathered with the survey do not provide information of the date on which the measures were implemented. In the Var and the West, this low rate may be related to the absence of PPRs and PPR related studies and provision of information. It appears from these results that there is room for improvement of the incentives provided by towns and insurers.

According to the results of the survey, the subsidy system which includes the Barnier fund does not incite households to implement mitigation measures. However, this fund was also created to finance the relocation of households exposed to natural hazards that pose a considerable threat to human lives. The number of respondents who moved because of a previous flood in the Ardennes (6) and in the Var (7) is low. In contrast, in the West, 48 households moved because of a previous flood. 44 of these respondents used to live in Charron which was badly hit by the 2010 flood. The relocation of these households was regulated by the government and has been financed with the Barnier fund. This result provides a first insight into the potential capacity of this fund to incite households to move out of their flood-prone homes. Households could have refused to relocate, but very few did so (Savidan, 2011). This suggests that the finances provided by the Barnier fund were adequate to convince people to move out of the floodplain.
2.4.4 Other factors of influence on flood damage mitigation behaviour of households

Figure 2-5 provide results on the relation between the percentage of respondents who took structural (Str), avoidance (Av), and emergency preparedness (EmP) measures and four factors which have been found in the literature to have an important influence on households’ mitigation behaviour. These factors are flood experience (Siegrist and Gutscher, 2006; Kreibich and Thieken, 2009) and three coping appraisal variables which have been highlighted as a main driver of flood mitigation behaviour in a literature review by Bubeck et al. (2012a). The coping appraisal variables are defined here as the perceived self-efficacy (SE), which is the perceived ability of the respondents to implement the measures, the perceived response-efficacy (RE), which is the perceived effectiveness of the measures, and the perceived response-cost (RC), which is the perceived costs to implement the measures (Grothmann and Reusswig, 2006).

Figure 2-5 (a) shows that respondents who have been flooded seem to take slightly less structural and avoidance measures than respondents who have never been flooded. This outcome may also be the result of the effectiveness of structural and avoidance measures if respondents were never flooded because of the mitigation measures they took. However, the difference is small. Respondents who have been personally flooded do appear to take slightly more emergency preparedness measures than respondents who have never been flooded. Figure 2-5 (b) and (c) indicate that the perceived self-efficacy and response-efficacy have an influence on the implementation of structural and avoidance measures. In particular, respondents with the highest perceived self-efficacy and response-efficacy took more measures. Perceived self-efficacy and response-efficacy do not appear to be related to the implementation of emergency preparedness measures. Figure 2-5 (d) shows that the perceived response-cost is related to the implementation of structural and avoidance measures. Respondents with the highest perceived response-cost took fewer measures than respondents with the lowest perceived response-cost. Perceived response-cost does not appear to be related to the implementation of emergency preparedness measures.

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12. SE, RE, and RC were measured separately for structural measures and for non-structural measures. The question for SE was: “Do you feel that you or a member of your household has the capacity to implement most of the measures described above?” The answers were: very much able; able; not able, not unable; unable; not able at all. The questions for RE and RC both started with: “How do you rate the following aspects of the measures described above? They are…” For RE, the answers were: very effective; effective; not effective, not ineffective; not effective; not effective at all. For RC, the answers were: very cheap; cheap; not cheap, not expensive; expensive; very expensive.
Flood damage mitigation investments

a - Not flooded or flooded

b - Perceived SE
Figure 2-5. Percentage of respondents who implemented structural (Str), avoidance (Av), and emergency preparedness (EmP) measures for respondents who: (a) have never experienced a flood or have personally experienced at least one flood; (b) have a low (SE1), medium (SE2), or high (SE3) perceived self-efficacy; (c) perceive the response-efficacy of the measures to be low (RE1), medium (RE2), or high (RE3); (d) perceive the response-cost of the measures to be low (RC1), medium (RC2), or high (RC3).

Stimulating flood damage mitigation through insurance
2.5 Suggestions for improvement of the CatNat system

2.5.1 Suggestions relating to households’ financial security and mitigation behaviour

Section 2.2 shows that the CatNat system provides reasonably good financial security for households since 80 per cent to 90 per cent of the requests for natural disaster decrees have been granted by the government. Combined with the results from Section 2.4 which show that damage reimbursements can be used by homeowners to rebuild their houses in a less vulnerable manner, it appears that the compensation scheme can facilitate household investments’ in mitigation measures. However, a drawback of this is that the high financial security provided by the CatNat system can decrease the willingness of homeowners to take flood protection measures (Kunreuther et al., 2009) if households expect that their flood damage will be compensated regardless of the mitigation efforts that they have (not) undertaken. In addition, results from the survey show that certain mitigation measures are only rarely implemented by households and that most households did not receive incentives from their insurer to undertake mitigation measures. These findings could be remedied via two means. First, adequate and additional information can be provided on the risk faced by policyholders and the mitigation measures that are prescribed by PPRs and, in general, that are at the disposal of the policyholders. In particular, it is important that insurers incite households which have experienced flood damage to rebuild their homes in such a way that they are less vulnerable to floods. According to the results of the survey, it appears that certain households who experienced floods would already implement mitigation measures when restoring their home. Further research could examine the type of measures that households install during restoration of the home and the influence of insurers on these choices. Second, insurers have some means to encourage household compliance with the community’s PPR since after a natural disaster has been declared, insurers can decline compensation if five years after its approval there is non-compliance with the PPR’s mitigation prescriptions. However, this derogation has seldom been applied (Cour des comptes, 2009). In principle, following the procedure to refuse compensation could create an incentive for households to take mitigation measures and prevent payouts of insurers to non-compliant policyholders. Policyholders should then be made aware of this derogation possibility both from their insurer and their town when buying an insurance policy and when a PPR is being applied or approved. However, for consumers’ and political interests it may be more desirable to actively stimulate mitigation ex ante floods instead of denying compensation ex post flood events.
2.5.2 Suggestions for increasing the effectiveness of PPRs and mitigation measures

Results drawn from existing studies and reports discussed in Section 2.3 show that PPRs can, in some cases, limit new constructions in flood-prone areas and limit or avoid flood damage. However, these results are mixed, and the results used from the existing analyses may appear anecdotic or inconclusive. In addition, the results of the survey show that only few households implemented their mitigation measures after receiving incentives from their town. These results also show that other factors such as coping appraisals influence the implementation of mitigation measures. Based on these results, suggestions can be made to increase the effectiveness of PPRs. In particular, there appears to be a need for: making PPRs more adequate for local needs; standardised hazard definitions and PPR procedures; and increased implementation capacity. This could facilitate the realization of PPRs and improve protection against disasters. On the other hand, costs for the government increase, since it would have to set the standards and apply and approve a higher number of PPRs that are adapted to suit local needs. The compliance of communities with PPRs could be improved by imposing legal sanctions, such as fines, in case of non-compliance, while new rules could be established in order to help and monitor the realisation of the PPRs and the implementation of the PPR measures. Although information provided on flood risks and incentives from third parties may not have a strong effect on households’ mitigation behaviour, providing detailed information on mitigation measures may be effective in increasing flood preparedness. Households could be provided with additional information on the measures prescribed in the PPRs as well as on the costs, complexity, and conditions of implementation of the measures, and on their cost-effectiveness in reducing the risk. To provide such information, there is a need for increased knowledge of flood risks and of which types of flood risk mitigation measures are cost-effective. Additional incentives to ensure the revision of the PPRs could also help guarantee the adequacy of the prescribed measures.

2.5.3 Suggestions for improving the deductibles’ adjustment and increasing the implementation of PPRs

Modifying the conditions of the deductibles’ adjustment can be useful to increase the number of PPR applications. For instance, such modifications could include changing the requirements to start the adjustment so that it would start sooner; making the adjustment dependent on the level of flood damage to increase applications of PPRs in areas prone to low-probability floods or with a high exposure to flooding; and making
the deductible, as well as the adjustment, (partially) dependent on the flood risk faced by a community. These suggestions could limit the financial security of households living in areas with a high probability of flooding. However, they could potentially increase the financial security of insurers and of the government by enabling households to partially pay for the high costs of floods. In flood-prone areas, the deductibles would increase, which could provide an incentive for households to settle in non-vulnerable zones and to take mitigation measures to reduce their flood risk (Kunreuther et al., 2009). It could also influence households to pressure their community officials to ask for, and implement, PPRs. Concurrently, the increase in deductibles could only be limited – not stopped – after the application decree for a PPR is signed and until the PPR is approved, and stopped when it is approved. The adjustment would then provide an incentive for the approval of the PPRs and not only for their application. An alternative could be that the adjustment would only be stopped when the compulsory measures of the approved PPR are implemented by a given proportion of community households. The effectiveness of stimulating flood preparedness through a modification of the deductibles’ adjustment has not been empirically examined in France. Further research on this subject could therefore be of interest (see also Section 2.5.5).

2.5.4 Suggestions for improving mitigation grants

According to the findings of the survey, the results of the French subsidy system are mixed. The survey findings show that the Barnier fund appears to have been successfully used in the West of France to relocate households whose homes were considered to be subject to a non-acceptable level of flood risk. Survey findings also show that subsidies were not used by households to finance the implementation of their mitigation measures, even though the costs of the measures appear to be a factor influencing the decision to (not) implement structural and avoidance measures. In order to increase the use of subsidies by households, the allocation of the funds could be made less dependent on PPR applications and approvals, and could instead provide financial resources on the basis of the level of flood risk and the mitigation measures to be taken by vulnerable households. Also, households could be provided with (additional) information on available subsidies and efficient risk-reducing measures. It should be noted that increased availability of subsidies could result in an increased demand for grant money, which would require an increase in the funds’ financial capacity. Providing funds to individuals, instead of communities or groups, could be time-consuming and costly for the government.

Given the aforementioned problems with the financial stability of the Barnier fund, other means could be examined to fund mitigation measures. Some researchers pro-
pose the development of affordable loans that could be used by households to pay for mitigation measures (Kunreuther, 2006). Moreover, subsidies such as additional tax reductions, income support, or vouchers could be provided by the government to low-income households in order to provide them with the financial means to invest in mitigation measures. Such subsidies could prove to be costly for the government, especially because they would need to be provided on an individual basis. These subsidies would have to be monitored and efficiently provided to ensure that the mitigation measures are actually implemented, and prevent the situation whereby the subsidies give low-income households an incentive to settle in vulnerable areas.

2.5.5 Changing the fixed premiums and deductibles to increase incentives for mitigation

Apart from the diverse suggestions for improvement of the CatNat system mentioned in this section, a broader modification of this scheme could be envisioned to increase the incentives for damage mitigation by households. Fixed premiums have the advantage that they provide a high financial security for households living in flood-prone areas. However, they also have the disadvantage that the level of natural disaster premiums that people pay does not depend on their actual flood risk. This limits incentives for mitigation since insurers cannot encourage households to take risk-reducing measures. In order to encourage damage mitigation by households, insurers could therefore charge risk-based premiums that provide policyholders with a price signal of the flood risk they face (Schwarze and Wagner, 2004; Kunreuther et al., 2009). Risk-based premiums can limit the incentives to settle in flood-prone areas, because the awareness of the risk and the costs of living there increase. Also, risk-based premiums can provide a direct monetary benefit to policyholders who undertake mitigation measures in terms of a premium reduction that reflects the reduction of risk induced by mitigation (Van den Bergh and Faure, 2006; Botzen et al., 2009b). Similarly to differentiating primary insurance premiums, reinsurance premiums could be differentiated according to risk, which could provide an incentive to insurers to stimulate their clients not to settle in high-risk areas or to invest in mitigation measures (Niehaus and Mann, 1992).

The effectiveness of stimulating flood preparedness through differentiation of insurance premiums (and deductibles; Section 2.5.3) has not been empirically examined in France. A reform of the CatNat system is currently under way based on a study conducted with expert consultation which concluded that risk-based premiums would be beneficial for communities and big companies, but would not be accepted for small companies and households (Projet de loi, 2012). Introducing risk-based pre-
miums for households may be complicated because of the need for detailed spatially differentiated information on flood risk and because it may conflict with the solidarity principle. Further research on the subject could nonetheless be of interest in order to improve incentives for risk reduction and prevention in France.

### 2.6 Conclusions

The CatNat system was created in France in 1982 in order to provide compensation for damage caused by floods and other natural hazards. This system is based on the principle of national solidarity, which in practice means that the compulsory natural disaster coverage is provided through a premium-financed reserve in combination with fixed premiums. Several regulations, such as Risk Prevention Plans (PPR), have been created in order to limit new constructions in hazard-prone regions and reduce the vulnerability of buildings to natural hazards. Results of a review and a survey conducted among 885 households in three flood-prone areas of France in 2011 show that the CatNat and PPR regulations provide a strong financial security to households, while the implementation rates of some mitigation measures by French households living in flood-prone areas are very high. These are important strengths of the French CatNat system. However, results also show that overall levels of flood preparedness can be improved and that the current regulations and insurance incentives play only a minor role in households’ decisions to prepare for flooding. Given the projected increase in future flood risk, the question arises whether the current system can effectively accommodate these risks, for example, through the stimulation of damage mitigation by households.

Several improvements of the CatNat system have been proposed in this chapter aimed at stimulating the undertaking of damage mitigation measures and, thereby, increase the resilience of France to flooding. This study provides several ideas for the growing number of researchers, insurers, and policy makers who are working on the creation or the improvement of insurance-related flood management policies. An overview of these improvements and their implications is provided in Table A-1 in Appendix A. Among the suggestions for improvements are differentiating insurance premiums, as well as deductibles, according to flood risk, increasing the incentives for PPR applications and approvals, increasing the effectiveness of PPRs, and improving the monitoring of the implementation of mitigation measures. In addition, ideas for further research are highlighted, which include the need for empirical research in France on the effectiveness of risk-based premiums in encouraging mitigation behaviour.

Flood damage mitigation investments
3 Factors of influence on flood damage mitigation behaviour by households

Abstract

Based on a literature review, this chapter proposes and empirically tests an extended version of the Protection Motivation Theory (PMT) of individual disaster preparedness. A survey was completed by 885 households in three flood-prone regions in France. Regression models provide insights into the factors of influence on the implementation of three categories of flood risk mitigation measures and households’ intentions to implement (additional) measures. Although the results differ per category, the overall findings show that threat appraisals have a small effect on mitigation behaviour, while coping appraisals have a more important influence. Several variables that have been added to the PMT framework appear to be influential in households’ preparedness decisions, such as: flood experience; local flood risk management policies and incentives; and the social network. Based on these results, two policy recommendations are made for increasing individual flood preparedness: improving communication campaigns on flood damage mitigation measures, and providing additional financial incentives.
3.1 Introduction

Since 1982, properties in France have been covered for natural disasters via a natural disaster coverage called the CatNat system, which is compulsory and included in home insurance contracts. This coverage has been linked to Risk Prevention Plans, or in original French, “Plans de Prévention des Risques” (PPRs13), which aim to limit new construction and enforce the implementation of prevention measures by communities and households in flood-prone areas. However, research has shown that there is scope to improve incentives for the undertaking of mitigation measures by households. Chapter 2 shows that between 6 per cent and 82 per cent of flood-prone households implement cost-effective flood risk mitigation measures, and that most households who implemented measures did so for other reasons than existing incentives.

An emerging literature exists on the factors of influence on households’ flood damage mitigation behaviour, such as risk perceptions or coping appraisals (Grothmann and Reusswig, 2006; Bubeck et al., 2012a). In addition, several studies have highlighted flood experience as a dominant factor of influence on flood preparedness (Siegrist and Gutscher, 2008; Kreibich and Thieken, 2009; Bubeck et al., 2013). Recent research suggests that it would be useful to further study household perceptions and behaviour across different regions, since flood preparedness may differ with respect to the local characteristics of flooding (Bubeck et al., 2012b; Kellens et al., 2012).

The overall objective of this chapter is to offer insights into individual flood preparedness decisions for flood risk management policy in France. Through a literature review and results obtained from a household survey conducted in 2011 in three French regions that face different kinds of flood risks, this chapter has aimed to provide answers to the following question: To what extent do households implement flood damage mitigation measures, and what are the factors that influence individual decisions to prepare for flooding? To answer this question, an extended version of Protection Motivation Theory (PMT) has been applied, which explains households’ decisions to prepare for risk using threat and coping appraisals, among other factors.

PMT was originally formulated by Rogers (1975), and later revised by Rogers (1983), to explain how individuals protect themselves against health risk. It has been used by Grothmann and Reuswig (2006), Zaalberg et al. (2009), and Bubeck et al. (2013) in

13. PPRs consist of flood maps and complementary guidance reports for the management of flood-prone areas (see Section B2, Appendix B).
the context of flood risk. PMT predicts that individuals will protect themselves against a particular hazard if they think that the threat of the hazard that they face ('threat appraisal') is high, and if coping appraisals are high. The latter is the case if individuals perceive that the available protective measures are effective (high ‘response-efficacy’), easy (high ‘self-efficacy’), and not too costly to implement (low ‘response costs’). The extended version applied here includes five additional components as shown in Figure 3-1 that have been extracted from a literature review (Section B1, Appendix B): flood experience; risk attitudes; flood risk management policies; social networks and social norms; and socio-economic factors.

![Figure 3-1 An extended framework of Protection Motivation Theory. Source: Adapted from Grothmann and Reusswig (2006) and Bubeck et al. (2012a).](image)

3.2 Methods

3.2.1 Survey method and description of the sample

A survey was conducted among households in three flood-prone areas in France in 2011 (Figure 3-2), in order to assess the level of implementation of flood damage mitigation measures and the factors that influence these households’ flood risk mitigation behaviour. The three areas are the Ardennes, the Var, and the West Coast.
These areas differ with respect to: flood history, the types of floods occurring, existing regulations against floods, and local flood management approaches. These characteristics are described in Chapter 1. The survey was conducted in villages and towns that were carefully selected on the basis of having experienced flood event(s) in the past. This selection of areas was made using flood maps of PPRs and observations and discussions with local civil servants during visits of the case study areas. It was expected that the respondents would be well-prepared for flooding, because the benefits of flood damage mitigation measures are very high for this sample of respondents.

The survey was a mail survey which was extensively pre-tested in the same sample areas as those where the final survey was conducted (Chapter 2). Observations obtained with the pre-test were excluded from the final survey. The questionnaires were pre-tested with ten face-to-face interviews and a mail pilot that was organized by IPSOS. For this pilot, 200 letters were sent to the sample areas; 26 completed questionnaires were returned. The final survey was sent by postal mail to 8,201 households, which were equally divided over the three regions. In total, 885 respon-
dents, of which 530 respondents had been previously flooded, returned the mail survey, which corresponds to a response rate of 10.5 per cent.

A comparison between the statistics of the actual population, which are obtained from the Institut National de la Statistique et des Études Economiques (INSEE, 2013), and the socio-economic characteristics of the respondents shows that the sample is approximately representative with respect to gender and education levels, although very low and very high education levels are slightly under-represented. The sample has a slight over-representation of homeowners and high income households. Moreover, low-age groups are slightly under-represented and high-age groups are slightly over-represented: in particular, the average age of the respondents is 56.6 years old, and 45 per cent are over 60 years old.

### 3.2.2 Variables and the regression method

In order to assess the current level of flood preparedness by households, the respondents were asked whether or not they had implemented 24 measures which were selected on the basis of their capacity to reduce flood damage (ICPR, 2002; Boulet-Desbareau et al., 2005; Kreibich et al., 2005). These measures, which are described in Table B-1 in Appendix B, are classified by the authors into three groups: namely, structural measures; avoidance measures; and emergency preparedness measures (Kreibich et al., 2005; Grothmann and Reusswig, 2006; Bubeck et al., 2012b).

A variety of indicators have been used to measure the main components of the extended version of PMT (see Figure 3-1) which is tested in this paper. The effects of several variables that potentially influence mitigation behaviour are estimated using OLS regression models using the statistical software SPSS 20. Linear regressions are calculated in a stepwise manner. First, all the explanatory variables that are to be assessed according to the theoretical framework in Figure 3-1 are included in the model. Second, the (least) non-significant variables are excluded from the regression one by one until only variables with a significant coefficient (p-value<0.1) remain in the model. In order to avoid multi-collinearity, variables with a Pearson coefficient of correlation equal to or above 0.70 (Bryman and Cramer, 1994) are not included together in the same regressions. If such variables are statistically significant in the

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14. The main variables which have been excluded from the models are variables representing: the flood risk (probability×consequence) perception; the perceived impact of mitigation measures on the appearance or the value of the home; fatalism; information received and sought about the hazard; marital status; profession; and perceived responsibility for preparedness.
model, then only one of the correlated variables is included in the final regression: namely, the variable with the highest explanatory power (i.e. resulting in the highest $R^2$). Such correlations exist between variables of threat appraisal, coping appraisal, and socio-economic characteristics\textsuperscript{15}. There are four dependent variables and twenty five explanatory variables which are classified in seven categories (see Table B-3 in the supplementary material for the coding of these variables). Three of the dependent variables are defined, respectively, as the number of structural, avoidance, and emergency preparedness measures that have been implemented in the home of the respondents. The last dependent variable is a categorical variable representing the intentions of the respondents to implement (additional) measures in the near future. The examination of both the number of measures implemented and respondents’ intentions to implement (more) measures was conducted to estimate the differences between the factors of influence on intentions to act and actual implementations of measures. In addition, examining relations between threat appraisal variables and intentions may provide better insights into the relation between risk perceptions and protective behaviour, which may be reversed in the model of actually implemented measures because of a feedback loop (see Section B1 of Appendix B and Section 3.4.1). The categories of explanatory variables are shown in Figure 3-1 and are explained in Appendix B (Section B2).

### 3.3 Results

Overall 94 per cent of the respondents have implemented at least one of the 24 measures included in the survey. Moreover, 91.1 per cent, 76.6 per cent, and 20.6 per cent of the respondents, respectively, took at least one structural measure, one avoidance measure, and one emergency preparedness measure. The number of measures that have been implemented varies considerably between households and regions. Respondents in the Ardennes take more measures than respondents in the other regions; in particular, 15 of the 24 measures are implemented more often in the Ardennes, 6 of the 24 measures are implemented more often in the Var, and out of the 15 measures that have been implemented more often in the Ardennes, 11 are also implemented more often in the Var than in the West.

\textsuperscript{15} Perception of flood damage is highly correlated with households’ fear or worry for future floods; perceived response-efficacy is highly correlated with perceived usefulness of the measures; the time needed to implement the measures is highly correlated with the perceived ease of implementing the measures; the perceived difficulty and the perceived cost of avoidance and emergency preparedness measures are highly correlated; the perceived time to implement and the perceived cost of avoidance and emergency preparedness measures are highly correlated.
3.3.1 Factors of influence on flood preparedness

Table 3-1 provides the final results of a series of separate linear regression analyses which were conducted for each group of mitigation measures. The table shows the variables that are significant (p-value<0.1) in explaining the variations in the number of measures that have been implemented in each category. The variables explain the variance in flood preparedness by 19 per cent to 31 per cent, which indicates a good fit for these types of models.

The results show that the perceived flood probability does not significantly influence the implementation of flood risk mitigation measures. The results about the influence of the respondents’ perceived flood damage on mitigation behaviour are mixed. This variable is related negatively to the implementation of structural and avoidance measures, and positively to the implementation of emergency preparedness measures. Possible reasons for these mixed results are discussed in detail in Section 3.4.1. The significant positive coefficients of the interaction variable of damage perception and the dummy variable of the Ardennes for structural and avoidance measures approximately offsets the negative coefficients of damage perception for the complete sample. Following the approach described in Wooldridge (2003, pp.139-142), a t-test was performed to estimate whether the coefficients of damage perception are indeed statistically not different from zero for the Ardennes, and the result is that this hypothesis cannot be rejected.

The positive and significant coefficients of self-efficacy (SE) in the models about the implementation of structural and avoidance measures imply that individuals who find that they have a high ability to implement these measures are more likely to do so. Although the coefficient for the interaction variable of self-efficacy for avoidance measures and the dummy variable of the West is negative, a t-test shows that the total effect of SE (0.14-0.21) is not statistically different from zero in the West. The negative coefficients of the response-cost (RC) variable for time in the three models for implemented mitigation measures imply that those respondents who perceive these measures to be time-consuming are less likely to have implemented them. In the same way, perceived cost of the measures relates negatively to the implementation of structural measures. Perceived response-efficacy is insignificant.

Flood experience has a positive and highly significant effect on the number of avoidance and emergency preparedness measures taken by the respondents. Risk aversion is positively related only to the implementation of structural measures, albeit with a low significance level.
Table 3.1 Factors that influence the implementation of structural, avoidance, and emergency preparedness measures in three flood-prone areas in France.

<table>
<thead>
<tr>
<th></th>
<th>Structural measures</th>
<th>Non-structural measures</th>
<th>Emergency preparedness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 627</td>
<td>Avoidance measures</td>
<td>N = 615</td>
</tr>
<tr>
<td></td>
<td>R² = 0.31</td>
<td>N = 632</td>
<td>R² = 0.24</td>
</tr>
<tr>
<td>Standardized coefficients β</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Threat appraisals:

- Perception of flood probability: n.s.
- Perception of flood damage: -0.20***
- Interaction: Perceived flood damage x Ardennes: 0.18***

Coping appraisals:

- Perceived self-efficacy (SE): structural measures: 0.20***
- Perceived self-efficacy: non-structural measures: n.a.
- Perceived response-efficacy: n.a.

Perceived response-cost (RC) structural and non-structural measures:

- Time needed to implement the measures: -0.13***
- Cost of the measures: -0.08*

Flood experience: n.s.

Risk attitudes: Risk aversion: 0.07*

Flood risk management policies and incentives:

- Looked for information on flood protection: 0.07*
- Feeling of being protected by public measures: 0.10**
- Incentive from municipality (including PPRs): n.s.
- Incentive from insurers: 0.10***
- Incentive from others: 0.11***

Social network and social norms:

- Mitigation measures taken by friends, family, or neighbours: n.a.

Socio-economic characteristics:

- Age: 0.11***
- Income: n.s.
- Ownership of the home: 0.08**
- Education level: n.s.
- Size of the household: 0.07*

Location:

- Ardennes: -0.10 (n.s.)
- West: -0.14***

p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01, n.s. = not significant, n.a. = not applicable.

Notes: * Statistical tests conducted on the significance of the difference between the coefficients of the variables for the complete sample and for the interaction variables show that Ho cannot be rejected, the difference is not significant.
In general, several positive significant effects of the local flood risk management policies and incentives for flood preparedness can be observed. Respondents who have looked for information on protection measures took more structural and emergency preparedness measures than other respondents. The positive coefficient of ‘feeling protected by public measures’ shows that respondents who feel well-protected are more likely to have structural measures implemented in their home. Incentives from the municipality result in higher levels of implementation of emergency preparedness measures. Table 3-1 also shows that incentives from insurers increase the likelihood of respondents implementing structural and avoidance measures. Respondents who received incentives from others than their municipality or insurer also took more mitigation measures.

The social network of respondents has a positive and highly significant influence only on the implementation of emergency preparedness measures. Older respondents have more mitigation measures in place. Income is not significant in any of the models, while owners have more structural measures implemented in their home than tenants. Respondents with a higher education level implement more avoidance measures. The size of the household positively influences only the adoption of structural measures. The regional variables show that people living in the West are less likely to have structural measures implemented in their home than respondents living in the other two regions.

### 3.3.2 Factors of influence on intentions to implement (additional) mitigation measures

Table 3-2 shows the results of the regression model of respondents’ intentions to implement (additional) measures. This model explains 32 per cent of the variance in the dependent variable. It is examined how the number of already-implemented flood risk mitigation measures has influenced intentions to implement additional measures. The results show that these intentions are negatively influenced by the number of implemented structural measures, while the number of implemented non-structural measures (avoidance and emergency preparedness measures) has a positive significant coefficient. The perception of the flood probability is significantly and positively related to households’ intentions to implement mitigation measures in the Ardennes, as the interaction variable shows, but this effect is insignificant in the other regions. The positive and significant coefficient of self-efficacy (SE) in the model about intentions shows that individuals who have a high perceived ability to implement mitigation measures also have higher intentions to do so. The response-efficacy (RE) variables have a positive relationship with intentions, which shows that
respondents who expect the measures to be effective in reducing the damage also have higher intentions to implement additional measures. The negative coefficient of the interaction variable of RE and the dummy of the Ardennes in this model shows that the positive effect does not hold in that region; in fact a t-test shows that the total effect of RE is not significantly different from zero in the Ardennes.

Table 3-2 Factors that influence the intentions to implement (additional) flood damage mitigation measures in three flood-prone areas in France.

<table>
<thead>
<tr>
<th></th>
<th>Intentions (^{a})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 325</td>
</tr>
<tr>
<td></td>
<td>(R^2 = 0.32)</td>
</tr>
<tr>
<td></td>
<td>Standardized coefficients (\beta)</td>
</tr>
</tbody>
</table>

**Threat appraisals:**
- Perception of flood probability
- Interaction: Perceived flood probability \(\times\) Ardennes: \(0.07\) (n.s.)
- Perception of flood damage: n.s.

**Coping appraisals:**
- Perceived self-efficacy (SE) structural measures: \(0.12^*\)
- Perceived response-efficacy (RE) structural measures: \(0.13^{**}\)
- Perceived response-efficacy non-structural measures: \(0.13^*\)
- Interaction: RE non-structural measures \(\times\) Ardennes: \(-0.49^{**}\) \(b\)
- Perceived response cost: n.s.

**Flood experience:**
- Interaction: Flood experience \(\times\) Ardennes: \(-0.21^{**}\)

**Risk attitudes:**
- Risk aversion: n.s.

**Flood risk management policies and incentives:**
- Looked for information on flood protection: \(0.08^*\)
- Incentive from municipality (including PPRs): \(0.13^{**}\)
- Incentive from insurers: \(0.11^{**}\)
- Incentive from others: \(0.18^{***}\)

**Social network and social norms:**
- n.s.

**Socio-economic characteristics:**
- Age: \(-0.21^{***}\)
- Location:
  - Ardennes: \(0.07\) (n.s.)
  - West: \(-0.07\) (n.s.)
- Mitigation measures implemented:
  - Number of structural measures: \(-0.14^{**}\)
  - Number of non-structural measures: \(0.14^{**}\)

\(^a\) In this model the N decreased to 316 because the number of respondents who replied to the question that elicited intentions to implement additional measures is low (N = 436); \(b\) Statistical tests conducted on the significance of the difference between the coefficients of the variables for the complete sample and for the interaction variables show that Ho cannot be rejected, the difference is not significant.

Notes: * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01, n.s. = not significant.
Flood experience is not significantly related to the respondents’ intentions to implement additional measures, in the whole sample, while a negative coefficient of flood experience is observed for the Ardennes. This table also shows that respondents who have looked for information on protection measures have higher intentions to implement additional measures than other respondents. Incentives from the municipality, insurers, and others than the municipality and insurers result in higher intentions to implement additional mitigation measures in the future. Table 3-2 shows that older respondents have lower intentions to implement additional measures.

3.4 Discussion

3.4.1 Threat appraisals

According to PMT, high risk perceptions are generally associated with decisions to prepare for flooding (Grothmann and Reusswig, 2006; Bubeck et al., 2012a). However, when testing for the effect of threat appraisal on flood preparedness in cross-sectional surveys, it may be found that risk perceptions decrease after measures have been installed (Weinstein and Nicolich, 1993). The relation found between threat appraisal and actual mitigation behaviour may, therefore, be weak or negative (Bubeck et al., 2012a). Such a feedback loop can be observed in the results of Table 3-1 for the perceived flood damage of those respondents who have undertaken structural and avoidance measures who perceive their future flood damage to be lower, and for the perception of the flood probability which is not significantly related to already-implemented mitigation measures. An exception is the results for the Ardennes, where respondents who have undertaken structural and avoidance measures do not perceive their future flood damage to be lower or higher. In contrast the positive relationship between perceived flood damage and mitigation behaviour that PMT predicts can be observed in the model of emergency preparedness. This high perception of flood damage may be the reason behind respondents’ decision to implement emergency preparedness measures. These emergency preparedness measures may also act as a reminder of the risk and, consequently, increase the perception of the damage. The implementation of structural and avoidance measures may significantly reduce perceived flood damage, while this may not be the case with emergency preparedness measures which require individual action in advance of a flood before these measures can be effective in limiting damage. Also, emergency preparedness measures include the creation of a family emergency plan, which does not itself limit material flood damage.
A solution for the measurement issue related to the feedback loop in cross-sectional surveys is to examine how the intentions of respondents to implement additional mitigation measures relate to threat appraisals (Bubeck and Botzen, 2013). Indeed, Table 3-2 shows that the perceived flood probability in the Ardennes positively influences respondents’ intentions to implement additional mitigation measures, but perceived flood damage does not significantly influence these intentions. Overall, these results show that high damage and probability perceptions do not automatically translate into high levels of individual flood preparedness.

3.4.2 Coping appraisals

The result that perceived self-efficacy is significantly related to the implementation of mitigation measures as well as to the intentions to take measures is consistent with the findings of the literature (Grothmann and Reusswig, 2006; Peak et al., 2010; Loke et al., 2012; Mishra and Suar, 2012). An exception to this is the West region where increased perceived self-efficacy does not influence the implementation of avoidance measures. This may be due to the very destructive nature of coastal floods in that region, which makes perceived ability to implement non-structural mitigation measures a less important factor of influence on mitigation behaviour. Moreover, perceived self-efficacy does not significantly influence the number of emergency preparedness measures that are in place.

The perceived response-efficacy of the measures does not influence actual flood preparedness, but is a significant factor of influence on households’ intentions to implement additional mitigation measures, except for non-structural measures in the Ardennes. A possible explanation for this latter result may be that, because of the high frequency of flooding in this region, being prepared and living with floods has become a “way of life”, independent of the perceived effectiveness of mitigation measures.

Perceived response-cost and, in particular, the expected time needed to implement emergency preparedness measures plays an important role in the decision to imple-
ment such measures. This is intuitively clear, since time is an important implicit cost category of emergency preparedness measures and emergency measures s.s. The perception of the time needed to install the measures shows a strong relationship with all the three categories of implemented mitigation measures, which is consistent with the findings from other studies (Grothmann and Reusswig, 2006; Siegrist and Gutscher, 2008; Kreibich et al., 2011). The perception of the costs of preparedness influences only the implementation of structural measures, probably because these measures can be relatively costly. This finding suggests that providing (additional) subsidies to households could increase their investments in structural measures since survey results show that currently subsidies are not used by households to pay for their measures. In this respect, Chapter 2 shows that current subsidies for flood damage mitigation in France are insufficient and that rules regarding their use are confusing.

### 3.4.3 Flood experience, risk aversion, flood risk management policies and incentives, and the social network

The results also show that the inclusion of flood experience, risk aversion, flood risk management policies and incentives, and the social network variables in the extended model (Figure 3-1) was useful for obtaining insights into the factors that influence households’ flood preparedness.

Flood experience is often found in the literature to positively influence flood preparedness (Wind et al., 1999; Kreibich et al., 2005; Siegrist and Gutscher, 2008; Harries, 2012). From the results shown in Table 3-1 and Table 3-2, it appears that flood experience is positively related with the number of implemented non-structural mitigation measures, while this is in general not found for intentions to take additional measures. Nevertheless, the inclusion of an interaction variable of the flood damage experienced during the respondents’ last flood and a variable of the Ardennes shows that intentions to implement additional measures are positively related to the flood damage experienced in the Ardennes, while the other results remain the same. A possible explanation for these results may be that, because of the high frequency of flooding in this region, being flooded is part of the respondents’ life. Even though having experienced a flood in itself does not increase intentions to take additional measures, such intentions are positively related to the severity of past flood experiences in terms of expenses that respondents have incurred to repair their homes after the floods.
Risk-averse personalities have been shown by Thieken et al. (2006) to be positively related to flood damage mitigation behaviour. This is confirmed in the results for the implementation of structural measures, although the estimated relationship is small.

The results show that flood risk management policies and incentives have an important influence on flood damage mitigation behaviour. Feeling protected by public measures is generally found in the literature to have a negative effect on mitigation behaviour (Grothmann and Reusswig, 2006; Paul and Routray, 2011; Botzen and Vanden Bergh, 2012b). However, here it is found that this variable is positively related to the implementation of structural measures. To obtain better insights into this result, a regression has been conducted to estimate the factors which are significantly related to respondents’ feelings of being protected by public measures. The results of this regression (not reported here) show that, in particular, having received information on flood protection is positively related to the feeling of being protected. The positive relationship between the feeling of being protected by public measures and the implementation of structural measures may therefore be related to the access to information which appears to increase the feeling of being protected, as well as, indirectly, the number of mitigation measures implemented. Having looked for information on flood protection measures, and having received incentives from the municipality and from an insurer positively influences the implementation of measures, as well as intentions to do so. The influence of insurers may be related to information that they provide about flood preparedness. In addition, having received incentives from others than the municipality or an insurer positively influences all categories of mitigation behaviour, and the social network positively influences the number of emergency preparedness measures that respondents have taken.

3.4.4 Socio-economic characteristics

Our results confirm the conclusions drawn in the literature reviews by Bubeck et al. (2012a) and Kellens et al. (2012) that the evidence on the influence of socio-economic factors on flood preparedness is mixed, and varies between contexts. Age appears to be an important factor in explaining the mitigation behaviour. The older the respondents are, the more measures they took. This finding is consistent with the results found in the literature by Sattler et al. (2000), Miceli et al. (2008), and Mishra and Suar (2012). There may be a “time effect” where respondents who have lived the longest in the same (flood-prone) home and area will have taken more measures than other respondents over time. In contrast, older respondents are less willing to implement additional measures. Contrary to the results of Laska (1990), Sattler et al. (2000), and Lindell and Hwang (2008), but, in line with the results of Sims and
Baumann (1987), Kreibich et al. (2005), and Botzen et al. (2009b), the variable income is not significant in any of our models. Also, in line with the results found by Kreibich et al. (2005) and Mishra and Suar (2012), the variables of ownership of the home, education level, and size of the household are all positively correlated with respondents’ mitigation behaviour, although these effects differ per category of measures. The regional variables show that less structural measures are taken by respondents who live in the West of France, where floods are less frequent.

3.5 Conclusions

Using an extended version of Protection Motivation Theory, the results of this chapter show that threat appraisals have only minor effects on mitigation behaviour, while coping appraisals have a larger influence, especially on the implementation of structural measures and households’ intentions to take additional measures. In particular, the numbers of installed structural and avoidance measures as well as the willingness to take additional measures are positively related with individuals’ perceived ability to implement these mitigation measures (‘self-efficacy’). Individuals who perceived the mitigation measures as time consuming to install were less likely to take these measures, and fewer structural measures are put in place by individuals who perceived these as being costly (‘response costs’). Individuals who expect that flood damage mitigation measures are effective in reducing flood damage also have higher intentions to implement additional measures (‘response efficacy’).

The extension of PMT appears to be useful, since flood experience and local flood management policies and incentives are shown to be influential in households’ mitigation decisions. The results of the socio-economic characteristics of respondents are mixed, as has been observed in other studies. Differences in the factors of influence on households’ mitigation behaviour can be observed between the three case-study areas and the different categories of mitigation measures. These differences in results may be related to the particular types of floods and the frequency and severity of flooding that have been experienced in these areas.

Overall, the significant effects of the variables of flood risk management policies and incentives are encouraging, since they show that the provision of information and incentives can increase the number of flood damage mitigation measures that households put in place. In particular, two main recommendations for flood risk management policies can be identified from the results of the effects of the incentives and the coping appraisal variables on the number of implemented measures and their intentions to take additional measures. Although the effects of these individual vari-
ables differ slightly, overall they have a large influence on both dependent variables of mitigation behaviour, which provides a strong rational for these policy recommendations.

First, the provision of information on flood damage mitigation measures can be improved in order to better prepare households for flooding. Increasing the provision of information by the government, municipalities, and insurers could further encourage households to prepare for floods. Campaigns could provide information on the types of measures that are available to limit flood risk, how they can be implemented, and their effectiveness. This can increase households coping appraisals, and, thereby, improve flood preparedness.

Second, improved financial incentives could be provided to households who invest in costly structural measures, such as flood-proofing of buildings with water-resistant materials. Although, perceived high cost does not influence intentions to take additional measures, it appears to be an obstacle for the actual implementation of structural measures. Therefore, additional subsidies (or other financial incentives such as insurance premium discounts) could be granted for the implementation of expensive (but cost-effective) mitigation measures.
4 Potential of semi-structural and non-structural adaptation strategies to reduce future flood risk: case study for the Meuse

Abstract

Flood risk throughout Europe has increased in the last few decades, and is projected to increase further owing to continued development in flood-prone areas and climate change. In recent years, studies have shown that adequate undertaking of semi-structural and non-structural measures can considerably decrease the costs of floods for households. However, there is little insight into how such measures can decrease the risk beyond the local level, now and in the future. To gain such insights, a modelling framework using the Damagescanner model with land-use and inundation maps for 2000 and 2030 was developed and applied to the Meuse river basin, in the region of Limburg, in the southeast of the Netherlands and to the Belgium and French parts. The research for the Netherlands suggests that annual flood risk may increase by up to 185 per cent by 2030 compared with 2000, as a result of combined land-use and climate change. Projections of flood risk for the year 2030 show that flood risk in France is expected to increase between 13-36 per cent, depending on the climate change scenario. These projected increases in flood risk are substantially smaller than the expected increase in risk in the Netherlands. For the Netherlands, the independent contributions of climate change and land-use change to the simulated increase are 108 per cent and 37 per cent, respectively. The risk-reduction capacity of the implementation of spatial zoning measures, which are meant to limit and regulate developments in flood-prone areas, is between 25 per cent and 45 per cent (the Netherlands). Mitigation factors applied to assess the potential impact of three mitigation strategies (dry-proofing, wet-proofing, and the combination of dry- and
wet-proofing) in residential areas show that these strategies have a risk-reduction capacity of between 21 per cent and 40 per cent, depending on their rate of implementation. Combining spatial zoning and mitigation measures could reduce the total increase in risk by up to 60 per cent. For France, potential risk reductions for flood proofing and spatial planning are of course regionally dependent, but the effectiveness of these measures in reducing risk is broadly similar between the Netherlands and France. Dry-proofing can reduce flood risk up to 30 per cent in France and wet-proofing up to 20 per cent. The highest risk reductions can be obtained in Belgium where flood-proofing can reduce risk by more than 40 per cent in some areas. Policy implications of these results are discussed. They focus on the undertaking of effective mitigation measures, and possible ways to increase their implementation by households.

4.1 Introduction

In recent decades, flood damage throughout Europe has increased because of development in flood-prone areas (Barredo, 2009; Munich RE, 2010). Flood damage is projected to increase further as a result of continued urban development combined with climate-change effects on river discharges and flood probabilities (Aerts et al., 2006; Bouwer et al., 2006; IPCC, 2007; Te Linde et al., 2010; Ward et al., 2012). In the light of these developments, several studies are assessing changes in flood risk, where flood risk is defined as the probability of flooding multiplied by the potential consequences, such as economic damage or loss of lives (Maaskant et al., 2009; Merz et al., 2010). Flood risk is a function of: (a) the hazard; (b) the exposure; and (c) the vulnerability (Crichton, 1999; Poussin et al., 2012b). This definition is also used in influential reports on risk and climate change impacts (UNISDR, 2011; IPCC, 2012).

To manage current and future flood damage and risk, different adaptation strategies are available and have been studied. These strategies are diverse and include the use of technical measures to reduce the probability of flooding (e.g. Vis et al., 2003; Merz et al., 2010), the provision of flood protection such as storm surge barriers and dikes (Aerts and Droogers, 2004), the use of insurance to provide compensation, to help recovery, and provide incentives for damage mitigation (Kunreuther, 2006; Crichton, 2008; Paudel et al., 2012), the use of spatial zoning with increased control over land-use changes and developments of new and existing urban areas (Burby et al., 2000), and the use of damage reduction measures on houses, which are also called “mitigation measures” or flood-proofing measures (Kreibich et al., 2005; Kreibich and Thieken, 2009).
Several studies based on past floods and/or economic models have shown that adequate undertaking of flood-proofing measures can considerably decrease the costs of floods for households. These studies focus on avoided costs, damage reduction, and/or cost-benefit ratios. Wind et al. (1999) focus on the potential link between household preparedness and the 35 per cent decrease of the losses between the floods of 1993 and 1995 on the Meuse. ICPR (2002) provides ranges of damage reduction percentages for different flood damage mitigation measures. Kreibich et al. (2005) and Kreibich and Thieken (2009) provide data on the effectiveness of household flood-proofing measures in reducing flood damages in Dresden, Germany. ABI (2003) reports on the cost-effectiveness of 34 (mostly) semi-structural measures, for 5 different types of houses from semi-detached properties to bungalows, and 3 floodwater heights. Thurston et al. (2008) and Kreibich et al. (2011, 2012) are two studies focusing on the cost-benefit ratios of semi-structural flood-proofing measures and their relation with the probability of flooding. Despite these studies, there is still little insight into how semi-structural and non-structural measures can decrease the flood risk beyond the local level, now and in the future.

The main aims of this chapter are, therefore: (a) to assess the sensitivity of riverine flood risk to changes in land use and climate; and (b) to examine the potential of different adaptation strategies at the regional scale to reduce future flood damage and risk. The study is carried out for the case-study region of the Meuse river in the province of Limburg, in the southeast of the Netherlands. This assessment is the first study of this kind carried out in the Netherlands. Flood risk is assessed by using simulated damage results for multiple return periods in order to calculate the expected annual damage (EAD), which is estimated by integrating the area under an exceedance probability loss curve (i.e. risk curve) (Grossi and Kunreuther, 2005).

An inundation model called the Floodscanner model (Ward et al., 2011a) is coupled with a damage model called the Damagescanner model (Klijn et al., 2007; Aerts et al., 2008) to simulate damage and flood risk for the current situation and for future scenarios of land-use and climate change, with and without adaptation strategies at the regional scale. Adaptation strategies include spatial zoning measures and three types of flood-proofing measures: namely, dry-proofing, wet-proofing, and a combination of dry- and wet-proofing measures. The damage- and risk-reduction capacity of the adaptation strategies is assessed by using relative changes, since research shows that estimates of relative changes in flood damage are more robust than estimates of absolute changes (Bubeck et al., 2011).

The remainder of this chapter is structured as follows. Section 4.2 describes the case-study area. Section 4.3 explains the data and methods used. It includes a short de-
scription of the model and adaptation strategies. Section 4.4 presents the results of the damage and risk calculations, with and without adaptation strategies. It ends with an analysis of the geographical distribution of the risk and the effectiveness of the mitigation measures. Section 4.5 discusses the results, and conclusions are drawn in Section 4.6.

4.2 Case study: the Meuse in Limburg

4.2.1 The Meuse

The Meuse is a predominantly rain-fed river, with a length of about 875 km from its source in France to its mouth in the Netherlands. Its catchment area extends over parts of Belgium, France, Germany, Luxembourg, and the Netherlands, over an area of about 33,000 km². The Meuse basin is one of the most densely-populated areas of Western Europe, and is inhabited by about 9 million people. The river itself is navigable, and provides drinking water for about 6 million inhabitants (De Wit et al., 2007).

Mean annual precipitation over the basin is reasonably evenly distributed throughout the year. The Meuse has a relatively rapid response to rainfall, and is relatively sensitive to floods (Van Pelt et al., 2009), with flood waves mainly occurring during the winter half-year. The section of the Meuse studied in this research flows between the border of Belgium and the Netherlands (upstream) to river kilometre 166 (downstream) near the village of Mook (Figure 4-1). Along this section, the Meuse forms a natural border between Belgium and the Netherlands. During floods the river can therefore flood on both the Dutch and the Belgian side. In this study, we examine inundation, flood damage, and flood risk, only in the Dutch part. Section 4.5.5 of the discussion presents results for France of a parallel project that used a similar modelling approach. The Limburg Meuse occupies a terraced river valley (Van der Meulen et al., 2006). Unembanked sections can be inundated if river levels rise above the level of the bank. There are also several (relatively small) dike-ring areas along this section of the Meuse. Dike-rings are separate administrative units that are designed to withstand floods up to certain return periods (such as 250 years in the dike-rings along the Meuse in Limburg), in order to provide a certain level of protection against floods within the dike-ring areas (Poussin et al., 2010).
4.2.2 Past research on flood risk in the Meuse basin

Since the severe floods along the Meuse in 1993 and 1995, several studies have been conducted to analyse the past, present, and future hydrological behaviour of the river Meuse and the effects of climate and land-use changes on it (Bates and De Roo, 2000; De Wit et al., 2001; Jacquet et al., 2003; Pfister et al., 2004; Booij, 2005; Aerts et al., 2006; De Wit et al., 2006; Tu, 2006; De Wit et al., 2007; Ward et al., 2007; De Wit, 2008; Leander et al., 2008; Ward, 2008; Ward et al., 2008, 2009, 2011b); past flood damage (Loche, 1994; Van Meijgaard and Jilderda, 1996; Wind et al., 1999), and flood risk (Ward et al., 2011a). The results of hydrological models for the future generally project that mean winter-season discharge in the future will be greater than it was in the past, and the frequency of floods will increase.

The case-study area for this research was chosen for two reasons. First, relatively good data are available for setting up both the inundation and damage models. Second, while the area is relatively prone to flooding compared with the downstream sections of the Meuse where safety standards are considerably higher, it has received less attention in recent studies on flood risk in the Netherlands. Risk estimates have
been made for large Dutch dike-ring areas downstream of Mook in three major projects: Floris (Ministry of Transport, Public Works and Water Management, 2005); Nederland Later (Klijn et al., 2007); and Attention to Safety (Aerts and Botzen, 2011). Other studies have also investigated flood risk in those downstream dike-rings (e.g. Bouwer et al., 2009, 2010; De Moel et al., 2011).

Fewer studies have examined the upstream area of the Meuse in which this research is conducted. Ernst et al. (2010) assessed economic damage along two sections of the river Ourthe, a tributary of the Meuse in Belgium. Wind et al. (1999) reported observed (direct) damage in Dutch Limburg for the flood events of 1993 and 1995 of about 149 million euros (1993) and 91 million euros (1995)\(^{17}\) (in year 2000 euros). Van der Sande et al. (2003) simulated direct damage in the villages of Itteren and Borgharen in Dutch Limburg, and estimated property damage to be about 82 million euros (in year 2000 euros) for the 1995 Meuse flood. Ward et al. (2011a) studied the impact of the selection of inundation return periods on simulated flood risk. They showed that the simulated risk is highly sensitive to the selection of return periods used to derive the risk curve, ranging from 23 million euros per year up to 111 million euros per year, under the assumptions used in that study.

### 4.3 Data and methods

An overview of the methods, models, and data used is shown in Figure 4-2. For this research, flood risk is quantified as the expected annual damage (EAD). It is assessed by combining the damage results for different exceedance probabilities, and integrating the area under an exceedance probability loss curve (i.e. risk curve).

To assess the flood damage at different return periods, the Damagescanner model is used in combination with two types of scenarios: climate scenarios, and land-use scenarios. Land-use maps for 2000 and 2030 are used to represent the respective exposure. Inundation maps for nine different return periods, for climate 2000 and future climate 2030, are used to represent the hazard. Stage-damage functions represent the vulnerability by providing a relationship between inundation height, land use, and damage. To assess the potential impact of spatial zoning measures, the 2030 land-use maps are modified according to a spatial zoning project conducted in Lim-

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\(^{17}\) The original values (in Dutch guilders) were converted to euros (1 euro = 2.20371 Dutch guilders), and updated from 1993 and 1995 values to 2000 values, using GDP multipliers derived from Statistics Netherlands (http://www.cbs.nl).
Figure 4-2 Flow chart of the methods, models, and data used, with climate and land-use scenarios, and stage-damage functions. The Floodscanner produces the inundation maps. The Damagescanner calculates the damage and produces the damage maps used to assess the risk. Adaptation strategies include damage mitigation measures and spatial zoning. The flood risk is calculated as the area under an exceedance probability-damage curve (i.e. risk curve).
burg (see Section 4.3.3 ‘Adaptation strategies’). To assess the impact of the mitigation measures in residential areas, mitigation factors are applied to the stage-damage functions. Since research shows that there are high uncertainties associated with estimates of absolute changes in flood damage, and that estimates of relative changes are more robust (Bubeck et al., 2011), the damage and risk increases, as well as the damage- and risk-reduction capacity of the adaptation strategies, are assessed using relative changes.

### 4.3.1 Inundation modelling: Floodscanner and climate-change scenarios

To generate the inundation maps used for this research, an inundation model is used that was developed for a previous study on the Meuse, the Floodscanner model (Ward et al., 2011a). The model uses a simple zero-dimensional planar-based approach, conceptually similar to that of Priestnall et al. (2000). This allows for the rapid simulation of the large number of inundation maps required in this study. Since the model is not hydrodynamic, it is assumed that upstream flooding does not lead to a reduction in discharge downstream, leading to an overestimation of downstream inundation depths. However, Ward et al. (2011a) previously carried out a validation of Floodscanner for the Meuse river in Dutch Limburg, and found that it performed well compared with images of the historical floods of 1993 and 1995, as well as compared with results from a process-based 2-D hydrodynamic model (WAQUA: provided by Rijkswaterstaat Dienst Limburg). The maps in Figure 4-3 show the few locations which did not perform as well. For example, the modelled maps show an inundation area at the confluence of the Niers tributary and the Meuse (shown by circle a in Figure 4-3). Here, the simplified inundation model has difficulty in dealing with hydraulically complicated backwater effects. A second source of anomalies is around several of the new ‘Maasplassen’; these lakes were created by sand and gravel mining, and some were completed post-1995 (for example the Lange Vlieter, shown by circle b in Figure 4-3). Hence, these lakes are ‘inundated’ in the model, but were not inundated in 1993 and 1995 because at that time the gravel and sands had not been extracted.

The model is raster-based with a spatial resolution of 50m × 50m. It uses stage-discharge relationships to estimate the water level for different discharges, and creates a planar surface representing the water surface. Using a Digital Elevation Model (DEM), the inundation depth is deduced from the difference between the water level and the elevation. Several steps are required, to: 1. derive the river network raster; 2. develop stage-discharge relationships; 3. simulate the planar water level surface; and 4. estimate flood inundation depth:
1. Derive the river network raster: we developed the river network raster based on a DEM derived from elevation data used in the WAQUA model of the Meuse. These data were provided by Rijkswaterstaat Limburg (RWS Limburg), as a Triangulated Irregular Network (TIN) map (WAQUA-version 2005-02, configuration J09 4). These data are rasterised to a spatial resolution of 50m × 50m. For areas outside the WAQUA configuration, the AHN5 (Actueel Hoogtebestand Nederland) DEM was used, which covers the Netherlands at a resolution of 5m × 5m. Again, this DEM was resampled to a resolution of 50m × 50m;

2. Develop stage-discharge relationships: stage-discharge data were used from the Meuse WAQUA schematisation J09 4, supplied by RWS Limburg. The rating curves give stage height at each river kilometre, for discharges of different return periods (up to 1250 years) at St. Pieter (upstream, near the Belgian-Dutch border); i.e. the downstream stages refer to specific return periods upstream. The stage-heights downstream account for lateral discharges from side-rivers, the main one being the Roer;
3. Simulate planar water level surface: discharge at Borgharen (upstream) is given to the model as input. The model then estimates a corresponding water level at each river cell based on the stage-discharge relationships described above. All grid-cells in the study area are assigned to their nearest river kilometre grid-cell based on the Euclidean distance, leading to a theoretical planar water-level surface;

4. Estimate flood inundation depth: the elevation of each cell is subtracted from the planar water level surface, to give an inundation depth per grid-cell. Inundated cells not connected to the river via a flow-path with direct connectivity are removed. Furthermore, there are about 40 small dike-rings in the case-study area that provide protection against floods with return periods up to 250 years. These dike-rings are therefore not allowed to flood at discharges lower than the 250 year return period value (for each scenario).

The Floodscanner model is then used to simulate inundation levels for all return periods from 2 to 1250 years (i.e. 1250 return periods in total), based on the current climate data. The discharge magnitudes corresponding to each return period are derived using a Generalised Extreme Value (GEV) distribution, fitted on discharge time-series for the period 1961-1990 simulated using the HBV model, and reported in full in Droge et al. (2010). However, in most practical applications, it would be impractical and too time-consuming to compile this number of inundation maps to carry out flood risk assessment, and therefore it was decided to select a smaller number of inundation maps for our further analyses. Ward et al. (2011a) showed that the selection of the return periods used to calculate the risk, or EAD, has a large influence on the final risk estimate. Hence, we first calculated the risk based on all of the inundation maps, which resulted in a flood risk estimate of 34 million euros per year. We then selected the combination of nine inundation maps that gave the estimate of risk that was closest to the latter estimate. This resulted in the selection of inundation maps for return periods of 2, 5, 10, 20, 50, 100, 250, 251, and 1250 years; for this combination of return periods, the calculated risk is 31 million euros per year. The 251 year map represents the inundation at which dikes in Limburg are assumed to fail. The 1250 year map corresponds to the protection level for dike-rings in the Netherlands downstream from Limburg, and is an important return period in Dutch water management (Bouwer et al., 2010).

To assess the impact of climate change on the damage and the risk, two climate-change scenarios are used; the scenarios G and W+ for the Netherlands, which are based on the Intergovernmental Panel on Climate Change scenarios (IPCC, 2000). Scenario G corresponds to an increase in temperature by 2050 of about 1°C, while scenario W+ corresponds to an increase by 2050 of 2.3°C to 2.8°C (Van den Hurk et
Since the G scenario assumes a lower level of climate change than the W+ scenario, in this chapter these are defined as ‘climate low’ and ‘climate high’, respectively. The discharge magnitudes corresponding to each return period for each scenario are again derived using a Generalised Extreme Value (GEV) distribution, fitted on discharge time-series for the period 2021-2050 simulated using the HBV model (Drogue et al., 2010). The simulated discharge at Borgharen corresponding to each of the return periods used in this study, and for the three climate scenarios (2000, 2030 low, and 2030 high) are shown in Table 4-1.

<table>
<thead>
<tr>
<th>Return period</th>
<th>2000</th>
<th>2030 low</th>
<th>2030 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1589</td>
<td>1693</td>
<td>1716</td>
</tr>
<tr>
<td>5</td>
<td>1885</td>
<td>1957</td>
<td>2013</td>
</tr>
<tr>
<td>10</td>
<td>2112</td>
<td>2197</td>
<td>2278</td>
</tr>
<tr>
<td>20</td>
<td>2328</td>
<td>2453</td>
<td>2560</td>
</tr>
<tr>
<td>50</td>
<td>2720</td>
<td>2831</td>
<td>2950</td>
</tr>
<tr>
<td>100</td>
<td>2960</td>
<td>3072</td>
<td>3207</td>
</tr>
<tr>
<td>250</td>
<td>3258</td>
<td>3372</td>
<td>3523</td>
</tr>
<tr>
<td>251</td>
<td>3259</td>
<td>3373</td>
<td>3525</td>
</tr>
<tr>
<td>1250</td>
<td>3814</td>
<td>3933</td>
<td>4120</td>
</tr>
</tbody>
</table>

### 4.3.2 Damage modelling

**Damagescanner**

The damage calculations are conducted using the Damagescanner model. The Damagescanner has been used in a number of studies on the Rhine and the Meuse (Klijn et al., 2007; Bouwer et al., 2009, 2010; Aerts and Botzen, 2011; De Moel et al., 2011; Te Linde et al., 2011; Ward et al., 2011a). The model is used to calculate flood damage, from which the flood risk results are derived. It needs two inputs: an inundation map to represent the hazard, and a land-use map to represent the exposure. In the model, stage-damage functions (SDFs) are used for each land-use category to provide the relation between the inundation depth, the land-use type in each grid-cell, and the damage. Each land-use category has its own stage-damage function.
Land-use maps

To represent the evolution of land use in Limburg from the year 2000 to the year 2030, three maps are used: a reclassified CORINE Land Cover land-use map for 2000, and land-use maps for 2030 under two scenarios which were created using the Land Use Scanner (Loonen and Koomen, 2009). The Land Use Scanner simulations used in this study were developed for the Rhine and Meuse basins, and are described in greater detail in Te Linde et al. (2011). Each map represents the allocation of 13 land uses in Limburg, from residential areas of high and low density, to commercial, infrastructure, mines, recreation, nature, agriculture, cultivation, pasture, and inland water.

The future land-use maps are based on two future socio-economic scenarios, the “Global Economy” (GE) scenario and the “Regional Communities” (RC) scenario, which are, respectively, comparable to the A1 and B2 scenarios developed by the IPCC (IPCC, 2000). The Global Economy scenario is based on high economic and population growth. The land-use map, referred to in this study as ‘land use 2030 high’, shows a large increase in urban areas. The Regional Communities scenario is based on a low economic and population growth, a regional focus, and strict environmental regulations, including a restriction of new urban developments in the 100 year flood-zone. This scenario results in a land-use map, referred to as ‘land use 2030 low’, which shows a lower increase in urban areas. The land-use maps have a spatial resolution of 50m x 50m.

These land-use maps are based on simulations of land-use change resulting from projected socio-economic development, and, while spatial regulations are included via the economic scenarios, specific local and regional spatial planning measures and restrictions are not yet included. Hence, in some areas the Land Use Scanner may simulate urban development, whilst in reality this may be an area in which such development is not allowed under local or regional spatial planning regulations.

In order to assess different scenarios of damage and risk in 2030, in this study we linked the climate scenario G with the future land-use scenario of 2030RC, and the climate scenario W+ with the future land-use scenario of 2030GE (see Section 4.3.2.2 ‘Land-use maps’) (see also Bouwer et al., 2010).
4.3.3 Adaptation strategies

In order to assess the effects of adaptation strategies on the damage and the risk, we assess the effectiveness of several spatial zoning and mitigation measures using the Damagescanner model. The spatial zoning measures are used to modify the land-use maps. These measures, and their implementation in the Damagescanner model, are described below.

Spatial zoning

In the Province of Limburg, a spatial zoning project is currently being carried out in accordance with the ‘Beleidslijn Grote Rivieren (BGR)’ and the ‘Beleidsregels’, respectively, a Dutch law and the corresponding rules that are meant to limit and regulate developments in Dutch flood-prone areas (BGR zoning, 2012). The Rijkswaterstaat (RWS) Limburg provided GIS maps showing areas where either: (0) there are no restrictions; (1) new buildings and developments are not allowed, except if they are river-bound (e.g. harbour); and (2) new buildings and developments are allowed under certain conditions such as compensating for the loss of volume of water.

To assess the effect of the spatial zoning measures shown in these maps on flood risk in Limburg, we adapted the land-use maps for 2030 (simulated using the Land Use Scanner) to reflect the information contained in the BGR zoning maps. As such, areas in the BRG zoning maps that are planned to remain as they are now in the future (e.g. nature or agricultural fields), are sometimes projected to undergo new urban developments in the Land Use Scanner model. Hence, we modified these areas in the 2030 land-use maps by removing the new urban developments and replacing them with the land use from the 2000 land use map. With this spatial zoning measure, we assume that although the demand for urban development remains, that demand will be built outside of the flood-prone area since new buildings within it are not allowed.

Flood damage mitigation measures

To estimate the effectiveness of flood-damage mitigation measures on risk in residential areas, three mitigation strategies in Damagescanner are investigated, namely: 1. ‘dry-proofing’; 2. ‘wet-proofing’; and 3. the ‘combination of dry- and wet-proofing’. To implement these measures in the Damagescanner model, damage reduction factors (0 – 1) are developed to represent the proportion of damage that could be avoided at each inundation depth if the strategies were applied. These damage reduc-
tion factors are used to adjust the original SDFs in the Damagescanner model. The factors are based on a literature review, and are described in this section. For each strategy, two sets of reduction factors are developed to represent a low and a high range of effectiveness.

1. The dry-proofing strategy includes measures such as the use of sandbags, coffer dams, or panels on doors and windows, to stop the flood waters entering. According to the ICPR report (2002), such measures can decrease damage, if a flood occurs, by between 60 per cent and 100 per cent. Research shows that these measures are most effective up to one meter of water height, because above one meter the chance of wall failure due to water pressure increases (ICPR, 2002; EA, 2003; Boulet-Desbareau et al., 2005). The reduction factors chosen for this research are therefore 60 per cent reduction of damage per house up to one meter of water, for the low range, and 100 per cent reduction of damage per house up to one meter of water, for the high range. Above one meter of water, it is considered that the reduction of damage is 0 per cent.

2. The wet-proofing strategy includes all the measures, semi-structural and non-structural, that can be taken to adapt the exterior, interior, and uses of a house, in order to decrease the damage if flood waters enter the house. It includes measures such as: the strengthening of walls against water pressure; adapting the flood-prone parts of the house with waterproof materials; not keeping non-waterproof objects and furniture in flood-prone parts of house; moving vulnerable appliances to upper floors; installing one-way valves on water evacuation pipes to stop the waters from entering the house via the pipes; and storing paints and chemicals in the upper parts of the home. The ICPR report (2002) shows that such measures can reduce damage to house contents by up to 40 per cent, while according to Kreibich et al. (2005), these flood damage mitigation measures can reduce damage to buildings by between 36 per cent and 53 per cent, and to household contents by between 48 per cent and 53 per cent. The reduction factors chosen for our research are 35 per cent damage reduction up to two meters for the low range, and 50 per cent damage reduction up to two meters for the high range. Above two meters of water, previous studies have indicated that the damage-reducing capacity of wet-proofing measures strongly decreases (ICPR, 2002; ABI, 2003; Kreibich and Thieken, 2009). At such water levels, it is therefore considered that there is no reduction of damage, and hence the reduction factor is 0 per cent.

3. The third strategy examined in this study combines the dry-proofing strategy and the wet-proofing strategy; hereafter referred to as the ‘wet&dry-proofing strategy’. For this strategy, it is considered that a house can be protected by both wet
and dry proofing, i.e. by preventing the waters from entering the house as much as possible, while also adapting the house to decrease the damage in case waters enter. The reduction factors for the low range are equal, for each corresponding height, to the lowest factors of the dry-proofing strategy up to one meter (60 per cent), and the wet-proofing strategy up to two meters (35 per cent). For the high range, the reduction factors are equal to the highest factor of the dry-proofing strategy up to one meter (100 per cent) and wet-proofing strategy up to two meters (50 per cent). Above two meters of water the reduction factor is 0 per cent.

In a first step, these factors are applied to the residential high-density and residential low-density land uses, as if all houses, i.e. both existing and new buildings, are protected by the measures. Even though such wide implementation of the strategies is probably not feasible in practice, this calculation provides a maximum potential risk reduction that could be reached when applying the flood-proofing measures used in this study. In a second step, the mitigation factors are applied only to all the new residential areas in 2030, i.e. those areas that are classified as residential in the Land Use Scanner results for 2030 but are not residential in the land-use map of 2000. Hence, in this second step, the mitigation strategies are not applied to existing buildings, but only to all newly built houses until 2030. This simplification assumes that all new buildings would be flood-proofed, which is possibly more feasible than flood-proofing all existing and new buildings. This step is therefore useful for obtaining more realistic risk reduction results.

## 4.4 Damage and risk results

This section presents the results of the risk calculations, with and without adaptation strategies. The scenarios are defined as follows: 2000 scenario (i.e. climate 2000 combined with land use 2000); 2030 low scenario (i.e. climate 2030 low combined with land use 2030 low); and 2030 high scenario (i.e. climate 2030 high combined with land use 2030 high).

### 4.4.1 Flood-risk estimates without adaptation strategies

Table 4-2 shows the relative percentage changes in risk between the 2000 scenario and the future scenarios with land-use and/or climate change, without mitigation or spatial zoning measures.
The simulated risk in the 2000 scenario is 31 million euros per year. Compared with this scenario, the future scenarios show a risk increase of 97 per cent for the 2030 low scenario, and 185 per cent for the 2030 high scenario. The relative influence of land-use change on these increases is greater than that of climate change. The impacts of land-use change alone are increases in risk of 64 per cent and 108 per cent for the 2030 low and 2030 high scenarios, respectively, whilst the impacts of climate change alone are increases in risk of 20 per cent and 37 per cent (again for the 2030 low and high scenarios, respectively).

Table 4.2. Increase in EAD (risk) (in percentages), for the future scenarios (climate and/or land use) for 2030 compared with the 2000 scenario.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Percentage risk increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Climate 2000</td>
</tr>
<tr>
<td>2000</td>
<td>N/A</td>
</tr>
<tr>
<td>2030 low</td>
<td>64</td>
</tr>
<tr>
<td>2030 high</td>
<td>108</td>
</tr>
</tbody>
</table>

Figure 4.4 Damage results for the different climate and land-use scenarios, and for different exceedance probabilities, without adaptation strategies (exceedance probabilities on a log scale).
Figure 4-4 shows the damage results, plotted on a risk curve, for the different climate and land-use scenarios, without adaptation strategies. The impact of dike failure for a return period of 251 years or more (i.e. exceedance probability lower than 0.004), which is above the current safety standard of the dikes, is clearly visible in the figure, with much lower values for flood damage below this return period. 7

The relative increase in flood damage (in percentages) for different exceedance probabilities and future scenarios compared with the 2000 scenario is shown in Figure 4-5. The figure shows that, except for high probabilities, the simulated increases in damage as a result of land-use change only are greater than those for climate change only. According to our results, in relative terms the combined impact of land-use change and climate change on damage is greater for floods with higher probabilities, although in absolute terms the damage increase is smaller than it is for low probability floods.

![Figure 4-5 Increases in damage (per cent) compared with the 2000 scenario for the future climate and land-use scenarios, without adaptation strategies (exceedance probabilities are on a log scale).]

4.4.2 Risk-reducing capacity of spatial zoning measures

Table 4-3 shows the results when the land-use maps for 2030 are adjusted to include the BGR zoning currently implemented in Limburg. The impact of the land-use
change on the risk (and therefore the total risk increase in 2030) is much lower when
the BGR zoning is included. Compared with the 2000 scenario, land-use change
alone now leads to an increase in risk of 23 per cent for the 2030 low scenario, and
17 per cent for the 2030 high scenario. Compared with the 2000 scenario, the 2030
low and 2030 high scenarios would lead to an increase in risk of 48 per cent and 60
per cent respectively. The values in brackets show the risk reduction of the BGR
zoning when the results are compared with the risk without zoning for the same
scenario (for instance, the risk for the 2030 low scenario with zoning is compared
with the risk for the 2030 low scenario without zoning). These risk-reduction results
are the risk-reduction capacity of the measures. In this case, the BGR zoning alone
would decrease the risk by 25 per cent for the low scenarios, and by up to 45 per cent
for the high scenarios.

The results in Table 4-3 show that the increase in risk between the 2000 scenario and
the 2030 low scenario is almost equally due to the changes in land use and climate.
However, the same is not the case for the increase in risk between the 2000 scenario
and the 2030 high scenario. In the latter case, the relative impact of climate change is
now higher than that of land-use change. Moreover, if only changes in land use are
considered (assuming a constant climate 2000 scenario), the results show a greater
increase in risk between 2000 and 2030 for the low land-use scenario (23 per cent)
compared with the high land-use scenario (17 per cent). This is due to the BGR zon-
ing, which lowered the differences between the low and high future land-use scenar-
ios by counteracting the land-use evolutions projected by the Land Use Scanner.

<table>
<thead>
<tr>
<th>Land-use</th>
<th>Percentage risk increase (Percentage risk reduction of BGR zoning)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Climate 2000</td>
</tr>
<tr>
<td>2000</td>
<td>N/A</td>
</tr>
<tr>
<td>2030 low</td>
<td>23 (25)</td>
</tr>
<tr>
<td>2030 high</td>
<td>17 (45)</td>
</tr>
</tbody>
</table>

Table 4-3 Increase in risk (per cent) compared with the 2000 scenario for low and high climate and land-use scenarios, including BGR zoning. In brackets: risk-reduction capacity (per cent) of the BGR zoning, where the risk results with zoning are compared with the risk results without zoning, for the same scenarios.
4.4.3 Risk-reducing capacity of mitigation measures

Mitigation factors applied to all residential areas

The mitigation factors used to evaluate the damage- and risk-reduction capacity of mitigation measures correspond to the potential damage reduction for one protected house. To examine the maximum risk-reduction capacity of such measures, these factors are, in a first step, applied to all high-density and low-density residential land uses.

Figure 4-6 provides the flood risk estimates, in million euros, for the different mitigation strategies. The simulated risk for the 2000 scenario is 31 million euros per year. The absolute estimates are subject to high uncertainty but the relative changes between the 2000 and future scenarios give an indication of the order of magnitude of the change that can be expected. The projected increase in risk due to land-use and climate change (without adaptation) is not entirely compensated by the mitigation strategies; however, the strategies would decrease the risk from 61 and 89 million euros per year for the 2030 low and 2030 high scenarios, respectively, to about 43 and
53 million euros per year when the wet & dry-proofing strategy is implemented. The relative risk-reduction capacity of each measure, compared with no mitigation, can be seen in Figure 4-6. The relative reduction in risk ranges from 10 per cent for the wet-proofing strategy, when applied to the 2000 scenario, up to 40 per cent for the wet & dry-proofing strategy in the 2030 high scenario.

Figure 4-7 shows an example of the relative damage reduction, in percentage terms, induced by the different mitigation strategies. This figure represents the damage reduction induced by the mitigation strategies for the 2030 high scenario. The results of Figure 4-7 are similar to the results for the other scenarios (2000 scenario and 2030 low scenario). The effectiveness of the mitigation strategies is up to about 45 per cent for the wet & dry-proofing strategy for floods of return periods of 10 years (i.e. floods with exceedance probabilities of 0.1). For floods of a return period of 2 years (i.e. 0.5 exceedance probability) and for floods of return periods of 20 years to 250 years (i.e. 0.05 to 0.004 exceedance probability), the effectiveness of the strategies is lower, down to about 30 per cent for the wet & dry-proofing strategy. However, for floods of return periods higher than 251 years (i.e. 0.004 exceedance probability or lower, dike failure), the effectiveness of the strategies is between about 40 per cent and 45 per cent. Figure 4-8 shows that the dry-proofing strategy would have similar

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**Figure 4-7. Risk-reduction capacity (per cent) of the mitigation strategies applied to all residential areas. The reference scenarios are the results of the "No mitigation" strategy for each scenario (e.g. for the 2030 low scenario, the reference is the no mitigation strategy).**
results in reducing the risk to the wet & dry-proofing strategy. Figure 4-8 shows, however, that the strategies lead to different damage reductions for different return periods. For floods with a return period of 10 years or lower (i.e. exceedance probability higher than 0.1), the dry-proofing and wet&dry proofing strategies result in similar damage reduction. For lower exceedance probabilities, the dry-proofing strategy is less effective than the wet&dry-proofing strategy. This divergence is linked to the higher inundation depths that can be found during floods of lower probabilities, since the dry-proofing strategy is no longer effective during floods in excess of one meter depth.

Mitigation factors applied to new residences only

Since an implementation of the strategies to all residential areas is probably not feasible in practice, in a second step the mitigation factors are applied only to all the new residential areas in 2030, i.e. those areas that are classified as residential in the Land Use Scanner results for 2030, but are not residential in the land-use map of 2000. Accordingly, the risk results are higher and range from 53 to 70 million euros per year, while the risk reduction percentages are lower, ranging from 7 per cent to 21 per cent, (compared with 10 per cent to 40 per cent when all residential areas are
Figure 4-9 Risk results (expressed in terms of EAD) for low and high climate and land-use scenarios (in million Euros per year), for the different adaptation strategies (i.e. spatial zoning and mitigation measures) applied to all residential areas.

Figure 4-10 Risk-reduction capacity (per cent) of the different adaptation strategies (i.e. zoning and mitigation measures) applied to all residential areas. The references are the results of the “No mitigation” strategy for each scenario (for instance, for the 2030 high scenario with zoning, the reference is the “No mitigation” strategy).
flood-proofed). The damage reduction induced by the mitigation strategies for the 2030 high and 2030 low scenarios are as high as 25 per cent and 14 per cent, respectively, compared with the same scenario without mitigation. Contrary to the results in Figure 4-8, the effectiveness of the strategies is not the highest for the most uncommon floods. Similar to the results in Figure 4-8, for floods with an exceedance probability higher than 0.1, the dry-proofing and wet&dry proofing strategies result in similar risk reduction. This similarity decreases for lower exceedance probabilities.

### 4.4.4 Risk-reduction capacity of combined spatial zoning and mitigation measures

In a final step, the BGR spatial zoning measures are combined with the mitigation measures to assess the potential impact on flood risk of the combination of the different adaptation strategies. Mitigation factors are applied to the land-use maps corrected with the BGR zoning, and to all residential areas.

Figure 4-9 represents the flood risk estimates, in million euros per year, when the different adaptation strategies are combined. In the 2030 low and high scenarios (no adaptation), the simulated risk is 61 and 89 million euros per year, respectively. The combination of spatial zoning and mitigation measures could decrease the risk in 2030 by about 40 per cent for the 2030 low scenario (i.e. from 61 to 36 million euros per year), and by almost 60 per cent for the 2030 high scenario (i.e. from 89 to 36 million euros per year). Figure 4-10 shows the relative risk-reduction capacity of each mitigation measure, compared with the risk results for each scenario when no mitigation is implemented. For instance, the risk for the 2030 high scenario with zoning and wet&dry-proofing strategy is compared with the risk for the 2030 high scenario with zoning when no mitigation is implemented. When spatial zoning measures are implemented, the additional relative reduction in risk of the mitigation measures ranges from 8 per cent to 27 per cent.

### 4.4.5 Geographical distribution of flood risk

Figure 4-11 (a) represents the geographical distribution of the risk in million euros per year without adaptation strategies. Figure 4-11 (b), (c), and (d) represent the spatial distribution of the risk-reduction capacity of the following adaptation strategies: (b) spatial zoning measures alone; (c) dry-proofing strategy alone; and (d) wet-proofing strategy alone. The risk and risk-reduction results are aggregated per muni-
Figure 4-11 (a) Risk results per municipalities, without adaptation strategies, in million euros per year; (b) Average risk-reduction results of spatial zoning (per cent); (c) Average risk-reduction results of the dry-proofing strategy (per cent); (d) Average risk-reduction results of the wet-proofing strategy (per cent).
Principalities in Limburg. The risk results in Figure 4-11 (a) are summed per municipality. The risk-reduction results are the averages per municipality.

Figure 4-11 (a) shows that the risk would be highest in three areas: namely, in the northern, upper-central, and southern sections of the region. The upper-central section corresponds to the area around Venlo (35,000 inhabitants), and the southern section corresponds to the area around Maastricht (120,000 inhabitants). In these areas, as well as in the northern section, the high risk results are linked to both the high inundation depths and the high exposure of assets in these urban areas. However, Ward et al. (2011a) show that, in the northern section of the Meuse in Limburg, Floodscanner tends to overestimate the inundation extent, and therefore the damage. The high risk results in that region may therefore also be partly linked to the overestimation of the Floodscanner model.

According to Figure 4-11 (b), (c), and (d), there are large geographical differences in the risk-reduction results of the adaptation strategies, which may be interesting to local decision makers. The highest risk-reduction results of spatial zoning are in the southern and central parts of the case-study area. The southern section corresponds to the area around Maastricht. From Figure 4-11 (c) and (d), it appears that the highest reductions in risk for both the dry- and the wet-proofing strategies would be realised in the same geographical areas.

### 4.5 Discussion

#### 4.5.1 Comparison with past research

Our results suggest that flood risk in Limburg may increase by 97 per cent and 185 per cent under the 2030 low and high scenarios respectively, compared with the 2000 scenario. These results are slightly lower than the risk increase results obtained by Te Linde et al. (2011) for the Rhine, which for the 2030 high scenario (climate W+, land use GE) were up to 230 per cent. However, Te Linde et al. (2011) only assessed risk based on extreme floods with a very low probability, and did not take different probabilities into account. Bouwer et al. (2010) estimated risk increases for dike-ring 36 of the Meuse river basin, north of our case-study area. When asset value increases are not included in the calculations, the authors projected increases in risk between 2000 and the future of 50 per cent and 334 per cent (for low and high scenarios, respectively). Hence, the projected risk increase for the future low scenario is similar to that of this chapter, whilst for the future high scenario it is higher. These differences
occur because: (a) the time-horizon of the future scenarios used in the study of Bouwer et al. (2010) is 2040, compared with 2030 in this chapter; and (b) the current and projected land-use patterns differ between the two regions.

### 4.5.2 Effect of spatial zoning measures

According to the projections of land-use and climate change used in this study, land-use change plays a larger role in the risk increase than does climate change. This is an important finding, since local and regional stakeholders have more control over the distribution of land use (e.g. Janssen et al., 2008) than over the evolution of the climate. Adequate land-use management could significantly decrease the overall risk compared with a situation without these measures. Indeed, when the already ongoing BGR zoning is included in the model, the risk is significantly decreased. However, the simulated risk still increases between the 2000 and the future scenarios, although the relative impact of land-use change becomes much lower when the BGR zoning is included. Other examples of the assessment of existing land-use management programmes in Europe can be found in the literature. For example, Ledoux (2009) and Vinet (2010) describe the French land-use management programme (e.g. Risk Prevention Plans or ‘Plan de Prévention des Risques’), and show their mixed results after more than 15 years of implementation, although no quantitative evaluation of the damage and risk reduction has yet been carried out. In the UK, White and Richards (2007) describe the main concerns arising from the land-use management programme, while Dawson et al. (2011) estimate the potential risk reduction of several adaptation measures, including land-use planning policies.

### 4.5.3 Effectiveness of the mitigation strategies

The results show that the maximum risk-reduction capacity of the mitigation strategies is up to 21 per cent and 40 per cent, when implemented only on new buildings in 2030 and in all residential units, respectively. Also, the dry-proofing strategy is more effective in reducing the risk than the wet-proofing strategy. This result differs from the findings of Kreibich et al. (2005) and Kreibich and Thieken (2009), which are based on past floods of the Elbe river in Dresden, Germany. The authors found that, during the floods of 2002, and compared with households who had not undertaken mitigation measures, households that had materials available for the undertaking of dry-proofing measures (e.g. private water barriers) did not experience as large a decrease in damage as households that had undertaken wet-proofing measures (e.g. flood-adapted use and flood-adapted interior fittings). However, the difference with
our results could be related to the fact that the flood of 2002 was an extreme event and private water barriers were overtopped, and had no or little effect (Kreibich et al., 2005).

Additionally, for high probability floods (10 year return periods and less), the dry-proofing strategy has a similar damage reduction capacity to the wet&dry-proofing strategy. This can be explained by the high mitigation factor chosen for the dry-proofing strategy, which is up to 100 per cent reduction of the damage for inundation depths lower than one meter, combined with low inundation depths (e.g. under one meter) which are found during high probability floods. Based on these results, and considering that dry-proofing measures are easier and less expensive to implement than wet-proofing measures (Kreibich and Thieken, 2009), dry-proofing measures seem to be a particularly interesting option to decrease the damage for houses affected by high probability floods. These measures could be implemented prior to, or instead of, implementing wet-proofing measures in these areas, although the results also show that wet-proofing measures can also significantly decrease the damage. Further knowledge on the cost-efficiency of dry- and wet-proofing measures would provide additional ground for decision-makers to choose which measures to implement. Such knowledge could have a large impact on the relative attractiveness of the measures.

When the measures are applied to all residential units, the damage reduction capacity of the wet-proofing strategy is the highest for lower probability floods (return period greater than 250 years). In areas exposed to low probability floods, the widespread implementation of wet-proofing measures (i.e. on both existing and new residences in 2030) would therefore seem particularly suited to decrease the high level of damage that can be expected.

4.5.4 Policy implications

The results of this study show that the already-implemented spatial zoning measures, combined with mitigation measures, could significantly decrease the future risk (see also Aerts et al., 2008). After carrying out preliminary analyses, a workshop was held in Limburg with several regional decision makers to discuss the results, and refine the methods for the final analyses. During the workshop, an important remark was made that there are currently no legal means in Limburg, and in the Netherlands, to enforce the undertaking of mitigation measures by households. Further discussion would therefore be needed before the implementation of these measures could be considered. It would also be interesting to assess methods to stimulate households to
implement measures. Incentives include measures such as limiting the financial intervention of governments to incite households to take measures prior to floods instead of relying on their government’s help after the flood (Kunreuther, 2006); regulating constructions with building codes (Camerer and Kunreuther, 1989; Kunreuther, 2006); providing adequate information to households in flood-prone areas (Sims and Baumann, 1987; Camerer and Kunreuther, 1989; Neuwirth et al., 2000; Grothmann and Reusswig, 2006); and implementing financial incentives such as insurance incentives, where insurers would increase premiums when households live in flood-prone areas, and decrease them if households take measures which are effective in reducing the risk (Camerer and Kunreuther, 1989; Kunreuther, 1996; Botzen et al., 2009a; Botzen et al., 2009b). The existing literature on this subject could serve as a useful starting point for such an analysis.

4.5.5 Flood-proofing results for France

As part of a parallel project to the paper presented in this chapter, the same modelling approach (‘Damagescanner’) was applied to the entire Meuse basin including the French part (Ward et al., 2012). The main results for France of that basin wide study are briefly summarized here. Although the overall model approach is similar as described in Section 4.3, some input data differs. In particular, for Wallonia stage-discharge curves were taken from the SOBEK-Meuse model (Van der Veen, 2007) and for France the stage-discharge relationships were derived from data available from EPAMA Banque Hydro (Banque Hydro, 2015). The SRTM DEM (Jarvis et al., 2008), and were used as input for the Floodscanner model.

Projections of flood risk for the year 2030 show that flood risk in France is expected to increase between 13-36 per cent, depending on the climate change scenario (Ward et al., 2012). These projected increases in flood risk are substantially smaller than the expected increase in risk in the Netherlands. Figure 4-12 and 4-13 present the results of the reduction of flood risk in the Meuse river basin that can be obtain by dry- and wet-proofing buildings. Although the obtained risk reductions are regionally dependent, the effectiveness of these measures in reducing risk is broadly similar between the Netherlands and France. The highest risk reductions can be obtained in Belgium.

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18. This sub-section was not part of the original paper by Poussin et al. (2012) on which this chapter is based. This sub-section summarizes results that originate from a report (Ward et al., 2012) of which Jennifer Poussin was a co-author.
Figure 4-12 Potential reduction in risk (per cent) in the 2030 high scenario as a result of “dry-proofing”. Results are aggregated to NUTS3 regions. Source: Ward et al. (2012).
Figure 4-13 Potential reduction in risk (per cent) in the 2030 high scenario as a result of “wet-proofing”. Results are aggregated to NUTS3 regions. Source: Ward et al. (2012).

4.5.6 Limitations of the study and future research

The modelling framework used in this study is relatively simple, but it does allow for assessing the sensitivity of flood risk to climate and land-use change, and to several adaptation options, at a large geographical scale. However, the land-use maps are not very precise at the local level (e.g. street or neighbourhood level) (Schotten et al.,
2001; Bouwer et al., 2010; Te Linde et al., 2011), which means that the results should not be used at that level. Further research would be needed to increase the precision of the land-use maps, while also including current policy decisions, such as spatial zoning, when using land-use models to simulate future land-use maps (e.g. Aerts et al., 2005). Additional modelling of the risk and damage on a wider scale (e.g. whole-basin scale) could also contribute to the discussion on the adequacy of household mitigation measures, spatial zoning, and the scale at which these adaptation strategies should be used. The spatial zoning measure as applied in this study assumes that although the demand for urban developments will remain, the new buildings will be built outside of the flood-prone area since new buildings within it are not allowed. This assumption can lead to an underestimation of urban development in flood-prone areas in the model. Therefore, additional modelling focused on the allocation of new construction areas under spatial zoning restrictions will have to be conducted to take into account the remaining demand for urban developments.

In addition, research and modelling with methods that allow for more precision on the degree of implementation of the mitigation measures at the town, region, or basin scale could further increase the precision of such a model. Methods to improve these results could include the gathering of data via workshops, interviews, or surveys. Modelling methods such as agent-based modelling could also prove useful in representing the behaviour of households. Finally, the mitigation factors used in this research were derived from the literature on the effectiveness of mitigation measures during past floods. Even though the differences in results with Kreibich and Thieken (2009) can be explained by the differences in inundation depths, further research on the subject of the effectiveness of mitigation measures in past and modelled floods could increase the precision of the model and the value of the results for decision makers. Including efficiency aspects of the measures – with the addition of knowledge such as the cost and the difficulty of implementing the measures – could also provide valuable input for decision makers (Bouwer et al., 2012; Jha et al., 2012; Meyer et al., 2012).

4.6 Conclusions

The first aim of this study was to assess the sensitivity of riverine flood risk in the Meuse to changes in land use and climate. In a future without implementation of the adaptation strategies studied in this paper, we projected an approximately two- to three-fold increase in risk (by 2030), with land-use change being the dominant driving factor. This highlights the need to implement adaptation strategies to limit the increase in risk.
This was addressed in the second aim, which was to examine the potential of different adaptation strategies at the regional scale to reduce future flood risk. The results show that currently ongoing spatial zoning projects can already reduce the increase in risk between 2000 and 2030 by up to 45 per cent. If implemented fully, the relative contributions of land-use and climate change to future flood-risk increase are of a similar order of magnitude.

Moreover, the flood-proofing of houses could further reduce future flood risk, and limit the risk increase that would occur without their implementation. The results show that the dry-proofing strategy has similar results in reducing the overall risk to the combination of dry- and wet-proofing strategies. Since dry-proofing measures are easier and less expensive to implement than wet-proofing measures, dry-proofing measures seem particularly attractive to reduce the risk. However, there are large geographical differences in the effectiveness of these mitigation measures. Flood-risk maps, such as those produced in this study, are useful to decision makers for understanding where flood risk hotspots are, and for identifying the strategies most likely to limit the risk in those areas.

This study shows that the strategies examined in this paper can significantly reduce flood risk; this is one of few studies to quantitatively assess the flood-risk reduction capacity of such strategies at the regional scale. However, there appears to be currently few means to enforce or encourage the undertaking of mitigation measures by households. Several methods may be used by governments and insurers to motivate households to implement such measures. Further research, providing local, regional, or basin level data on the damage- and risk-reduction capacity of adaptation strategies could therefore provide valuable input for decision makers, and stimulate discussions on the benefits of implementing and encouraging the implementation of these strategies.
Abstract

Recent destructive flood events and projected increases in flood risks as a result of climate change in many regions around the world demonstrate the importance of improving flood risk management. Flood-proofing of buildings is often advocated as an effective strategy for limiting damage caused by floods. However, few empirical studies have estimated the damage that can be avoided by implementing such flood damage mitigation measures. This study estimates potential damage savings and the cost-effectiveness of specific flood damage mitigation measures that were implemented by households during major flood events in France. For this purpose, data about flood damage experienced and household flood preparedness was collected using a survey of 885 French households in three flood-prone regions that face different flood hazards. Four main conclusions can be drawn from this study. First, using regression analysis results in improved estimates of the effectiveness of mitigation measures than methods used by earlier studies that compare mean damage suffered between households who have, and who have not, taken these measures. Second, this chapter has provided empirical insights showing that some mitigation measures can substantially reduce damage during floods. Third, the effectiveness of the mitigation measures is very regional dependent, which can be explained by the different characteristics of the flood hazard in our sample areas that experience either slow onset river flooding or more rapid flash and coastal flooding. Fourth, the cost-efficiency of the flood damage mitigation measures depends strongly on the flood probability faced by households.

5.1 Introduction

The importance of designing adequate flood risk management strategies has been illustrated by recent global flood events, such as Hurricane Sandy in the USA in 2012, or the large river floods in Germany and the UK in 2013, and 2014, respectively. Climate change may increase flood risks in many places around the world, which requires the implementation of strategies to manage current and future flood risks (IPCC, 2012). Such strategies include the provision of flood protection such as storm surge barriers and dykes as well as measures that reduce flood impacts (Botzen and Van den Bergh, 2009). Recent studies have shown that an adequate implementation of flood damage mitigation measures at the household level, with the aim of flood-proofing individual buildings, can decrease the costs of floods (Kreibich and Thieken, 2009; Bubeck et al., 2012b). Examples of such measures are installing flood barriers or anti-backflow valves, and elevation of the ground floor. Estimates of the effectiveness of such measures have been obtained by simulating flood risk reduction through flood risk assessment models (e.g. Dawson et al., 2011; Chapter 4), using expert judgment (ICPR, 2002; ABI, 2003; Defra, 2008), and empirical studies on avoided flood damage conducted after flood events (Kreibich et al., 2005; Kreibich and Thieken, 2009).

The few empirical analyses of flood damage avoided by private mitigation measures find that such savings can be large. After the Meuse floods in the Netherlands in 1993 and 1995, Wind et al. (1999) showed that the implementation of flood damage mitigation measures by households after 1993 decreased their flood losses by 35 per cent during the similar flood of 1995. Bubeck et al. (2012b) collected survey data on household flood preparedness during the Rhine floods of 1993 and 1995. They showed that flood damage to households was reduced by up to 50 percent during the 1995 flood as a result of implementing measures. Several studies conducted after the 2002, 2005, and 2006 floods of the Elbe river in Germany have also concluded that mitigation measures substantially reduce flood damage (Kreibich et al., 2005, 2011, 2012; Olfert and Schanze, 2008; Kreibich and Thieken, 2009). Kreibich et al. (2005) and Kreibich and Thieken (2009) estimated that the use of flood adaption for buildings and furnishing reduced the flood damage to buildings by between 46 and 53 per cent, and the flood damage to home contents by between 48 and 53 per cent. Installing heating and electrical utilities on higher floors, adapting the structure of the home to floods, and water barriers, respectively reduced the damage to buildings by 36, 24, and 29 per cent (Kreibich et al., 2005; Kreibich and Thieken, 2009).

Although the aforementioned studies provide useful insights into the potential damage savings from flood damage mitigation measures, it is evident that this empirical
literature is scarce and focused on a few river basins, which are located in a few countries (mainly Germany). Moreover, few studies examined the cost-effectiveness of these measures. Kreibich et al. (2011, 2012) estimate benefit-cost (B/C) ratios of adapting buildings to floods in Germany, which depend on the type of measures and homes as well as on the probability of flooding. In particular, securing oil tanks and installing water barriers turn out to be very cost effective with B/C ratios between 5.61 and 539.96, and between 1.12 and 61.14, respectively (Kreibich et al., 2011, 2012). These B/C ratios are calculated using values of flood loss reductions that are based on a comparison of means of flood damage suffered between groups of households who have, and who have not, taken flood damage mitigation measures. Applying regression analysis may be more suitable for estimating the independent effect of damage mitigation measures by controlling for other effects on flood damage, such as flood water heights (Wooldridge, 2003).

Further empirical research is needed on the (cost-)effectiveness of individual flood damage mitigation measures. Such information is imperative for policy-makers who are involved in the design of flood risk management policies, insurance companies who are interested in reducing flood vulnerability of their policyholders, and households and businesses who want to reduce the flood risk to their property (e.g. Kull et al., 2013). This study, therefore, aims to provide data on the (cost-)effectiveness of 11 different flood damage mitigation measures. Flood damage savings are estimated using regression models of data gathered by means of a survey of households who have experienced floods. This survey was conducted in three regions of France that face different flood risks. In total 885 households replied to the survey.

The remainder of this chapter is structured as follows: Section 5.2 describes the survey and methodology; Section 5.3 presents the results of the potential flood damage that can be avoided by the 11 flood damage mitigation measures, and the (cost-)effectiveness of these measures; and Section 5.4 provides a discussion and conclusion of the main findings of this study and their implications for flood risk management policies.

5.2 Description of the survey and methodology

5.2.1 Survey method and description of the sample

A mail survey was conducted in France in 2011 in three flood-prone areas: the French Ardennes; the Var; and the West Coast (Chapter 3). These three areas differ with
respect to their flood history, the types of floods they are subject to, their existing regulations against floods, their local “flood cultures” and flood management approaches. The Ardennes are mainly subject to large river floods, which occur regularly and can cause considerable damage, such as 120 million euros and 240 million euros in 1993 and 1995, respectively (EPTB, 2011). In the Var, households are regularly threatened by flash floods. In 2010, an extreme event occurred that caused 600 million euros and 23 deaths (FFSA, 2011). The West region faces coastal floods, which occur rarely. In 2010, the storm Xynthia caused 1.5 billion euros in damages, including 700 million euros flood damage, and 47 deaths (Anziani, 2010). More information can be found in Chapter 2. The survey was conducted in villages and towns that were carefully selected on the basis of having experienced flood event(s) in the past. The survey was pre-tested in the same sample areas that were used for the final survey (Chapter 2). The final survey was sent by IPSOS, a French professional survey research company, by postal mail to 8,201 households, which were equally divided over the 3 regions. In total, 885 respondents returned the mail survey, of which 530 have been personally flooded at least once in their home.

A comparison between the demographic statistics from the actual population of the three regions, and the socio-economic characteristics of the respondents who experienced flood damage can be found in Chapter 2. The sample is approximately representative with respect to certain characteristics, such as gender and education, while it slightly under-represents homeowners and over-represents high income and older households. Most age groups of adults are well represented in our sample, but higher age groups are slightly over-represented. As an illustration, the percentages of our regional samples that fall in the age group 60-74 years are 28 per cent, 24 per cent and 37 per cent in the Ardennes, the Var and the West, while in the actual population these percentages are 14 per cent, 18 per cent and 17 per cent. In general, older individuals in France tend to take more flood risk mitigation measures (Chapter 3). But, there is no reason to suspect that age affects the flood damage avoided per mitigation measure, which is the main focus of this paper.

5.2.2 Overview of the main variables included in the regression models

A variety of variables have been used to assess the effectiveness of the mitigation measures in reducing flood damage. The effects of several variables that potentially influence the level of flood damage are estimated using ordinary least squares (OLS) regression models. Linear regressions are calculated in a stepwise manner, thus excluding explanatory variables that are insignificant.
Table 5-1 contains a description of the dependent and explanatory variables that are included in the final regression models. The two dependent variables are the level of financial flood damage experienced by respondents to their home (the building) and to its contents. This damage data was elicited by asking respondents to give the monetary value of the damage they had experienced during their (last) flood. In line with Kreibich et al. (2005), we determine the damage ratio of the assets and of the contents by dividing the level of flood damage to the building or to the contents by the market value of the home or the value of contents respectively. In total, 374 and 357 observations were obtained for calculating damage ratios $Y/a$, for the buildings and the home contents, respectively, where, $Y$ is the flood damage experienced to the building or home contents and $a$ is the value of the building or the home contents.

Table 5-1 lists three categories of explanatory variables: the characteristics of the flood; the characteristics of the home; and the mitigation measures. The floods experienced by the respondents are defined by two characteristics: the maximum water height attained in the cellar and the maximum water height attained on the ground floor. The possible effect of the characteristics of the home of the respondents on the damage are accounted for by using three variables which are: living in a home within 100 meters of the source of the flood; living in a house (instead of in an apartment); and whether the home of the respondent includes a cellar. Water velocity is not included directly, which means that this effect is captured indirectly by the distance to the source of the flood variable. Interaction variables of the measures and the water height, and of the measures and the closeness to the source of the flood, are included in the regressions to assess the effect of the water depth and the distance to the source of the flood on the damage experienced by households who have, or have not, implemented flood damage mitigation measures. For two measures (i.e. walls and equipment made of water-resistant materials, and owning sandbags or water barriers), the interaction variables with the closeness to the source of the flood are not used in the regressions in order to avoid problems with multi-collinearity. These interaction variables have a Pearson coefficient of correlation larger than 0.7 with the variables of the measures themselves, which is a high level of correlation that can cause multi-collinearity (Bryman and Cramer, 1994). Since potential damage savings from having the ground level floor made of water-resistant materials does not depend on the water depth, the interaction variable of this measure with the water height on the ground floor is not used in the regressions.
### Table 5-1 Overview of the variables used in the statistical analysis and their coding.

<table>
<thead>
<tr>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage to buildings</td>
</tr>
<tr>
<td>Damage to home contents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Explanatory variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of the flood:</td>
</tr>
<tr>
<td>Water height in the cellar</td>
</tr>
<tr>
<td>Water height on the ground floor</td>
</tr>
<tr>
<td>Characteristics of the home:</td>
</tr>
<tr>
<td>Close to source of the flood</td>
</tr>
<tr>
<td>House</td>
</tr>
<tr>
<td>Cellar</td>
</tr>
<tr>
<td>Mitigation measures:</td>
</tr>
<tr>
<td>Elevated ground floor</td>
</tr>
<tr>
<td>Foundations strengthened</td>
</tr>
<tr>
<td>Walls and equipment made of water-resistant materials</td>
</tr>
<tr>
<td>Floor of ground floor made of water-resistant materials</td>
</tr>
<tr>
<td>Raised electricity meter</td>
</tr>
<tr>
<td>Raised power sockets on ground floor</td>
</tr>
<tr>
<td>Anti-backflow valves</td>
</tr>
<tr>
<td>Elevated boiler</td>
</tr>
<tr>
<td>Sandbags</td>
</tr>
<tr>
<td>Raised electrical appliances</td>
</tr>
<tr>
<td>Furniture adapted</td>
</tr>
</tbody>
</table>

Notes: 

- These variables include observations of respondents who were personally flooded but replied that they had no financial damage, as well as respondents who replied that they were not personally flooded while their neighbours were flooded. These respondents may have not experienced damage or been personally flooded because of mitigation measures taken prior to the flood, which is why these responses were included in the analyses as having zero flood damage; 
- The regression models include interactions of this variable with the variable of closeness to the source of the flood; 
- The regression models include an interaction of this variable with the variable of the water height at the ground floor; 
- This measure is excluded from the regression analyses because it has a direct effect on water depth and only an indirect effect on the damage.
In the final survey, respondents were asked whether or not twenty one mitigation measures were implemented in their homes (Poussin et al., 2013). These measures were selected using literature review (ICPR, 2002; ABl, 2003; Boulet-Desbareau et al., 2005; Defra, 2008) and the survey pre-test. Ten measures were not included in the regression models: seven measures were excluded because of the very low number of respondents who replied that they had implemented them, and three measures were excluded because they cannot directly reduce flood damage. Also, elevating the ground floor is not included in the regression analyses, because it is the only measure that has a direct effect on the water height in the home by limiting the amount of water which can enter the ground floor. Thereby, it only has an indirect effect on the damage itself. Results of the (cost-) effectiveness of this measure are presented jointly with the results for the other measures. The eleven remaining measures which are included in the models are described in Table 5-1.

5.2.3 Methodology used to assess the (cost-) effectiveness of the mitigation measures

First, a comparison of means of flood damage suffered by households who have, or have not, implemented a specific mitigation measure was conducted. The significance of differences in mean damage ratios was assessed using the non-parametric Mann-Whitney U test which does not rely on the assumption of normally distributed variables, which is an assumption made by the t-test (Siegel, 1957). Data on the flood damage variables and damage ratios were found to be not normally distributed. In a second step, regression models were estimated in which all the explanatory variables of Table 5-1 were included (Section 5.3.2). These regression models were conducted to assess the effectiveness of the measures in reducing damage independently of other factors that can have a significant impact on the damage, such as the water height or the distance of the homes to the river or the sea. In a third step, using the coefficients of the regression models represented by equation 1, the effect of the implementation of each of the mitigation measures on the damage to buildings and to home contents was assessed for an average respondent (Section 5.3.3, Table 5-3).

\[ Y/a = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 + \beta_3 \times X_1 \times X_2 + \beta_4 \times Z_1 + \beta_5 \times Z_1 \times X_1 + \beta_6 \times Z_1 \times X_2 + \beta_7 \times Z_2 + \beta_8 \times Z_2 \times X_1 + \beta_9 \times Z_2 \times X_2 + \beta_{10} \times Z_3 + \beta_{11} \times Z_3 \times X_1 + \beta_{12} \times Z_3 \times X_2 + \ldots + \beta_n \times Z_n + \beta_n \times Z_n \times X_1 + \beta_n \times Z_n \times X_2 + \epsilon \] (Eq.1)

Where, ‘\(Y\)’ is the flood damage, ‘\(a\)’ is the value of the home or of the home contents, ‘\(\beta_0\)’ is the constant, the other betas are the unstandardized coefficients of the linear regression, ‘\(X_1\)’ is the water height, ‘\(X_2\)’ is the distance to the source of the flood, and
the ‘\(Z\)’ are the dummy variables of the mitigation measures, which take on the value 1 when the mitigation measure is implemented by the respondent, and 0 otherwise. \(\varepsilon\) is the error term. The impact of a mitigation measure on flood damage was assessed using equation (1) without the error term by estimating the effect on the damage ratio \(Y/a\) of changing the level of the mitigation measure variable from 0 to 1, while keeping all other variables at their sample average values. Changes in the damage ratio were translated to absolute values of flood damage avoided using the average value of the home or home contents.

In a fourth stage, the values of damage avoided by the measures which were found to significantly reduce flood damage were used in a benefit-cost analysis to assess the cost-effectiveness of the measures (Section 5.3.3, Table 5-6). Total discounted benefits over the life-time of the flood damage mitigation measures (‘\(B_{\text{lifetime}}\)’) were calculated using equation (2): the average values of damage avoided obtained with equation (1) which correspond to the benefits for a flood event (‘\(B_{\text{flood}}\)’) were multiplied by the flood probability ‘\(P\)’ to obtain values of average flood losses reduced per year, defined as \(B_t\). These flood losses were discounted using the discount rate ‘\(r\)’ and the year ‘\(t\)’ over the time horizon ‘\(T\)’ for which the measure is in place. The discounted flood losses reduced per year were then added over the life-time of the measure (‘\(B_{\text{lifetime}}\)’). The obtained value corresponds to the maximum value the measures can cost to remain cost-effective.

\[
B_{\text{lifetime}} = \sum_{t=1}^{T} \frac{(B_t)}{(1+r)^t}
\]

The flood probabilities selected for these calculations are 1/1, 1/10, and 1/50 years (Kreibich et al., 2011, 2012). Flood probabilities differ considerably between locations in French floodplains (Chapter 2). The broad range used here is representative for many inhabitants of floodplains in our sample areas. The applied discount rate is 4.5 per cent, which corresponds to the current discount rate in use in France since 1996 (Banque de France, 1997-2004, 2005-2013). The time horizon, or life-time of the measures, was set to 10 or 50 years depending on the life time of the specific measure (Table 5-6). Estimates of total costs of implementing the measures are provided, which were used to calculate Benefit-Cost (BC) ratios for the different mitigation measures per flood probability and region. When the cost of the measures is provided as a range, then the BC ratios were calculated for both the low and the high value of the range.
5.3 Survey results

5.3.1 Comparison of means of damage ratios

Table 5-2 provides a comparison of means of damage ratios, respectively, for the damage to buildings and to home contents experienced by respondents who did, or did not, implement a specific mitigation measure. In cases where the difference of means is significant, the table also provides the differences in flood damage to an average home in Euros and the percentage of the average reduction in the damage ratio that may be obtained by implementing the flood damage mitigation measure. The table shows that elevating the ground floor decreases both the damage ratio to buildings and to home contents by 48 per cent to 56 per cent, respectively. This damage saving is caused by a reduction in the water depth on the ground floor. In particular, elevation decreases the water depth in flooded homes on average by 0.26 me-

<table>
<thead>
<tr>
<th>Flood damage mitigation measures</th>
<th>Damage to buildings (N = 301 to 350)</th>
<th>Damage to home contents (N = 290 to 333)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean differences in ratios (mean differences in damage [Euros]): percentage reduction</td>
<td>Mean differences in ratios (mean differences in damage [Euros]): percentage reduction</td>
</tr>
<tr>
<td>Elevated ground floor</td>
<td>-0.03*** (€-7172): 48%</td>
<td>-0.10*** (€-5424): 56%</td>
</tr>
<tr>
<td>Foundations strengthened</td>
<td>-0.01</td>
<td>-0.002</td>
</tr>
<tr>
<td>Walls and equipment made of water-resistant materials</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Floor made of water-resistant materials</td>
<td>-0.02</td>
<td>-0.04</td>
</tr>
<tr>
<td>Raised electricity meter</td>
<td>-0.04*** (€-11365): 54%</td>
<td>-0.16*** (€-8885): 63%</td>
</tr>
<tr>
<td>Raised power sockets on ground floor</td>
<td>-0.07*** (€-18971): 84%</td>
<td>-0.18*** (€-10038): 77%</td>
</tr>
<tr>
<td>Anti-backflow valves</td>
<td>-0.03** (€-8585): 65%</td>
<td>-0.05* (€-2923): 38%</td>
</tr>
<tr>
<td>Elevated boiler</td>
<td>-0.04*** (€-11492): 60%</td>
<td>-0.12*** (€-6953): 63%</td>
</tr>
<tr>
<td>Sandbags</td>
<td>-0.01</td>
<td>-0.06</td>
</tr>
<tr>
<td>Raised electrical appliances</td>
<td>n.a.</td>
<td>-0.14*** (€-8056): 77%</td>
</tr>
<tr>
<td>Furniture adapted</td>
<td>n.a.</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

Notes: * p-value<0.1; ** p-value< 0.05; *** p-value < 0.01 estimated using the Mann-Whitney U test. n.a. stands for not applicable.

* The mean differences in flood damage experienced are calculated by multiplying the mean differences in ratios with the value of an average home, for each measure and type of flood damage.
ters for the entire sample, which is statistically significant \((p\text{-value}<0.001)\). Raising the electricity meter, the power sockets, and the boiler also significantly decreases the level of the damage ratio to both buildings and home contents from 54 per cent to up to 84 per cent. Anti-backflow valves decrease the damage ratio to buildings by 65 per cent and to home contents by 38 per cent, while raising the electrical appliances significantly reduces the level of the damage ratio to home contents by 77 per cent. The other measures do not significantly reduce the average flood damage. The differences in flood damage range from 2,923 to 18,971 euros per household. The highest reductions in damage caused to both the building (over 10,000 euros) and home contents (over 6,000 euros) are observed when the electricity meter, the power sockets, the boiler, and electrical appliances are raised.

### 5.3.2 Results of the regression models of flood damage to buildings and flood damage to home contents

Table 5-3 and Table 5-4 show the results of the regression models that include the variables that are significant in explaining the variations in the level of flood damage among our respondents, for the whole sample, and for each region separately. In Table 5-3 the variables explain between 36 per cent and 79 per cent of the variance in the damage. In Table 5-4 the variables explain between 62 per cent and 85 per cent of the variance in the damage. Overall, these results indicate that the models provide a good fit of the data.

**Damage to buildings**

**Overall sample**

The results from Table 5-3 show that the water height on the ground floor is strongly and directly related to an increase in damage. This finding is in line with various research using flood damage models, which shows that water depth is the main factor determining flood damage (Klijn et al., 2007; Bouwer et al., 2009, 2010; Aerts and Botzen, 2011; De Moel et al., 2011; Te Linde et al., 2011; Ward et al., 2011; Poussin et al., 2012a). Moreover, the results show that the effect of water depth on damage is slightly higher for respondents who live close to the source of the flood.

Strengthening the foundations has a negative, but insignificant effect on flood damage, while respondents with strengthened foundations who live close to the source of the flood have higher flood damage. This suggests that this measure is not effective in the overall sample.
Having the walls and equipment made of water-resistant materials does not decrease the damage to buildings. In contrast, it increases damage in the overall sample, especially when the water depth on the ground floor is high. This finding can reflect the strong correlation of the implementation of this measure with the variable living close by the source of flooding, which cannot be accounted for by an interaction variable because of the aforementioned problems with multi-collinearity. This means that the higher damage experienced by buildings made of water-resistant materials can occur because these buildings are generally located close by the river and the sea where flow-velocities are high. Alternatively, this result can arise if buildings made of water-resistant materials collapse in case of high flood water depths, as has been identified as a drawback of this measure by others (FEMA, 2009).

Using water-resistant materials for the ground level floor of the home does not significantly reduce the damage to buildings for the overall sample. A more effective measure is to raise the electricity meter which significantly reduces flood damage. Moreover, raising the power sockets on the ground floor significantly reduces the damage in the overall sample and it limits the negative effects on damage of high water levels.

Installing anti-backflow valves on pipes has an insignificant negative effect on flood damage in the overall sample, however, the effect of water depth is (weakly significantly) higher for respondents who implemented this measure. Elevating the boiler has an insignificant effect on flood damage in the overall sample.

**Regional sub-samples**

The sub-sample results confirm the significant influence of the water height on flood damage (Table 5-3). Moreover, the effect of water depth on damage is significantly higher for respondents who live close to the source of the flood in the Ardennes and the West.

Table 5-3 shows that, in the Ardennes, the effect of water depth on the ground floor on flood damage is smaller for households who strengthened the foundations of their home against water pressures than for other respondents. However, in the Ardennes, and the Var, this measure’s effectiveness is strongly reduced when households live close to the flood source. This suggests that strengthening the foundations is insufficient to prevent flood damage in areas close by a river or the sea where flow velocities of flood waters are high.
Table 5.3 Influence of mitigation measures and other variables on the level of flood damage to buildings in three flood-prone areas in France.

<table>
<thead>
<tr>
<th>Characteristics of the flood:</th>
<th>All regions</th>
<th>Ardennes</th>
<th>Var</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water height in the cellar</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.22**</td>
</tr>
<tr>
<td>Water height on the ground floor</td>
<td>0.08***</td>
<td>0.12***</td>
<td>0.07***</td>
<td>0.22***</td>
</tr>
<tr>
<td>Characteristics of the home:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close to source of flood</td>
<td>0.004</td>
<td>0.03</td>
<td>-0.002</td>
<td>-0.02</td>
</tr>
<tr>
<td>Close to source of the flood × Water height ground floor</td>
<td>-0.05**</td>
<td>0.16***</td>
<td>n.s.</td>
<td>1.11***</td>
</tr>
<tr>
<td>Mitigation measures:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundations strengthened</td>
<td>-0.005</td>
<td>-0.006</td>
<td>-0.002</td>
<td>n.s.</td>
</tr>
<tr>
<td>Foundations strengthened × Water height ground floor</td>
<td>n.s.</td>
<td>-0.35***</td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>Foundations strengthened × Close to source of the flood</td>
<td>0.05*</td>
<td>0.14***</td>
<td>0.10***</td>
<td></td>
</tr>
<tr>
<td>Walls and equipment made of water-resistant materials</td>
<td>0.02</td>
<td>n.s.</td>
<td>-0.004</td>
<td></td>
</tr>
<tr>
<td>Walls and equipment × Water height ground floor</td>
<td>0.04**</td>
<td></td>
<td></td>
<td>0.08*</td>
</tr>
<tr>
<td>Floor made of water-resistant materials</td>
<td>n.s.</td>
<td>-0.06***</td>
<td>-0.03*</td>
<td>n.s.</td>
</tr>
<tr>
<td>Raised electricity meter</td>
<td>-0.02*</td>
<td>0.04</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Electricity × Water height ground floor</td>
<td>n.s.</td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity × Close to source of the flood</td>
<td>n.s.</td>
<td>-0.10**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raised power sockets on ground floor</td>
<td>-0.02*</td>
<td>0.02</td>
<td>-0.007</td>
<td>-0.02</td>
</tr>
<tr>
<td>Power sockets × Water height ground floor</td>
<td>-0.06***</td>
<td>-0.11***</td>
<td>-0.15***</td>
<td>0.12**</td>
</tr>
<tr>
<td>Power sockets × Close to source of the flood</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.06*</td>
<td>n.s.</td>
</tr>
<tr>
<td>Anti-backflow valves</td>
<td>-0.02</td>
<td>n.s.</td>
<td>n.s.</td>
<td>-0.03</td>
</tr>
<tr>
<td>Anti-backflow valves × Water height ground floor</td>
<td>0.10*</td>
<td></td>
<td></td>
<td>-1.10***</td>
</tr>
<tr>
<td>Elevated boiler</td>
<td>n.s.</td>
<td>-0.03</td>
<td>-0.002</td>
<td>-0.008</td>
</tr>
<tr>
<td>Boiler × Water height ground floor</td>
<td>n.s.</td>
<td></td>
<td>0.12***</td>
<td>-0.24***</td>
</tr>
<tr>
<td>Boiler × Close to source of the flood</td>
<td>0.06*</td>
<td></td>
<td>-0.12***</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

* p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01, n.s. = not significant

The positive influence on flood damage of having the walls and equipment made of water-resistant materials found for the overall sample appears to be driven by the West where this coefficient is significant and positive. This measure has a non-significant influence on flood damage in the other regions.

Using water-resistant materials for the ground level floor of the home significantly reduces the damage in the Ardennes and the Var, while this measure was not significant in the overall sample. The damage reducing effect in the overall sample of raising the electricity meter appears to come from the Ardennes where it negatively reduces flood damage of respondents who live close to the source of the flood.
Effectiveness of flood damage mitigation measures

Raising the power sockets on the ground floor significantly compensates the effect of water depth on damage in the Ardennes and is related with a reduction in damage for higher water depths in the Var. In contrast, in the West this measure causes a slight increase in the effect of water depth on damage. This can be related to the speed of the flow during a coastal flood, making this measure less effective at high water levels. This effect can be mitigated in the West by installing anti-backflow valves on pipes since the effect of water depth on damage is smaller in the West for respondents who take this measure.

Elevating the boiler is insignificant in the whole sample, but has mixed regional results. In the Ardennes, this measure slightly reduces the damage. In the West, this measure reduces the effect of the water depth on the damage. In the Var, elevating the boiler reduces flood damage for respondents who live close by the source of flooding, but also increases the negative effects of water depths on damage, suggesting that it is ineffective if water levels are high.

Damage to home contents

Overall sample

The results from Table 5-4 show that higher water depths on the ground floor and in the cellar are significantly and directly related to an increase in the damage to home contents. Moreover, respondents who live close to the source of the flood have, in general, a lower flood damage level than respondents who live farther away from the river or the sea and the effect of water depth on damage is smaller for this former group of respondents.

Strengthening the foundations of the home against water pressures is not effective in reducing the damage to home contents. In fact, in the overall sample, the effect of the water height on the damage is higher for respondents who implemented this measure. This is consistent with results in the previous section showing that this measure is not effective in reducing flood damage to buildings.

Results show that using water-resistant materials for the walls and equipment reduces overall damage in the model of the whole sample, but this effect is not significant, while similarly as for the damage to buildings, this measure increases the effect of water depth on damage to home contents. Using water-resistant materials for the floor on the ground floor has a negative, but insignificant, effect on the overall flood damage for the overall sample, while this damage reducing effect is not present for households who live closer to the source of the flood.
Raising the electricity meter above the most likely flood level significantly reduces the flood damage to home contents in the overall sample, but this measure is ineffective for respondents who live close to the source of the flood. Anti-backflow valves do not significantly influence flood damage in the overall sample.

A priori we do not know whether people count damage to their boiler as building or contents damage which is why we include this measure in both regressions. It appears that elevating the boiler is not significantly related to the damage to home contents. A similar result is found for installing sandbags. Raising electrical appliances significantly reduces flood damage for the overall sample as a function of water depth.

**Regional sub-samples**

The significant positive effect of higher water depths on the ground floor is consistent for all the three regions. Moreover, in the Var, respondents who live close to the source of the flood have, in general, a lower flood damage level than respondents who live farther from the river or the sea. For respondents who live close to the source of the flood, the effect of water depth on damage is smaller in the Ardennes, while it is higher in the West. In the Ardennes and the Var, the findings can be the result of the high frequency of flooding in these regions that made respondents in flood-prone areas adapted to the risk.

It appears from Table 5-4 that the water depth in the cellar is associated with an increase in damage in the Ardennes. In the West, a higher water depth in the cellar is related to a reduction in damage to home contents. In particular, of the 73 respondents in this region, the 61 households who were not flooded in the cellar experienced more damage than the 12 households who were flooded in their cellar. This is probably due to the high number of households in this region that have flood-proofed their cellars.

The ineffective result of strengthening the foundations of the home against water pressures for the overall sample appears to be driven by the Var where this measure directly increases the level of damage experienced by households. The Ardennes appears to drive the ineffective result of using water-resistant materials for the walls and equipment which increases damage at high water levels. Using water-resistant materials for the floor on the ground floor reduces the overall flood damage in the Var, except for households who live closer to the source of the flood.
Table 5-4 Influence of mitigation measures and other variables on the level of flood damage to home contents in three flood-prone areas in France.

<table>
<thead>
<tr>
<th>Characteristics of the flood:</th>
<th>All regions</th>
<th>Ardennes</th>
<th>Var</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water height in the cellar</td>
<td>0.05***</td>
<td>0.05***</td>
<td>n.s.</td>
<td>-0.15**</td>
</tr>
<tr>
<td>Water height on the ground floor</td>
<td>0.31***</td>
<td>0.31***</td>
<td>0.09**</td>
<td>0.39***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristics of the home:</th>
<th>All regions</th>
<th>Ardennes</th>
<th>Var</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close to source of flood</td>
<td>-0.26***</td>
<td>0.09</td>
<td>-0.57***</td>
<td>0.05</td>
</tr>
<tr>
<td>Close to source of the flood × Water height ground floor</td>
<td>-0.08**</td>
<td>-0.20**</td>
<td>n.s.</td>
<td>0.33*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mitigation measures:</th>
<th>All regions</th>
<th>Ardennes</th>
<th>Var</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundations strengthened</td>
<td>0.009</td>
<td>n.s.</td>
<td>0.07**</td>
<td>n.s.</td>
</tr>
<tr>
<td>Foundations strengthened × Water height ground floor</td>
<td>0.08*</td>
<td></td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Walls and equipment made of water-resistant materials</td>
<td>0.001</td>
<td>-0.01</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Walls and equipment × Water height ground floor</td>
<td>0.08*</td>
<td>0.53***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Floor made of water-resistant materials</td>
<td>-0.04</td>
<td>n.s.</td>
<td>-0.13***</td>
<td>n.s.</td>
</tr>
<tr>
<td>Floor × Close to source of the flood</td>
<td>0.11**</td>
<td>0.28***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Raised electricity meter</td>
<td>-0.13***</td>
<td>0.31***</td>
<td>-0.40***</td>
<td>-0.11**</td>
</tr>
<tr>
<td>Electricity × Water height ground floor</td>
<td>n.s.</td>
<td>-0.32***</td>
<td>0.16***</td>
<td>n.s.</td>
</tr>
<tr>
<td>Electricity × Close to source of the flood</td>
<td>0.18***</td>
<td>-0.30***</td>
<td>0.30***</td>
<td>n.s.</td>
</tr>
<tr>
<td>Raised power sockets on ground floor</td>
<td>-0.03</td>
<td>-0.19***</td>
<td>-0.05</td>
<td>n.s.</td>
</tr>
<tr>
<td>Power sockets × Water height ground floor</td>
<td>-0.11***</td>
<td>n.s.</td>
<td>-0.11**</td>
<td>n.s.</td>
</tr>
<tr>
<td>Power sockets × Close to source of the flood</td>
<td>n.s.</td>
<td>0.18***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Anti-backflow valves</td>
<td>n.s.</td>
<td>-0.17**</td>
<td>-0.11**</td>
<td>n.s.</td>
</tr>
<tr>
<td>Anti-backflow valves × Water height ground floor</td>
<td>0.42***</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Elevated boiler</td>
<td>n.s.</td>
<td>-0.04</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Elevated boiler × Water height ground floor</td>
<td>0.27**</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sandbags</td>
<td>n.s.</td>
<td>0.14**</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sandbags × Water height ground floor</td>
<td>-1.22***</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Raised electrical appliances</td>
<td>-0.03</td>
<td>-0.01</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Electrical appliances × Water height ground floor</td>
<td>-0.13***</td>
<td>-0.35***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Furniture adapted</td>
<td>n.s.</td>
<td>-0.03</td>
<td>-0.15***</td>
<td>n.s.</td>
</tr>
<tr>
<td>Furniture × Water height ground floor</td>
<td>0.31***</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Furniture × Close to source of the flood</td>
<td>n.s.</td>
<td>0.31***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

*p-value < 0.1; **p-value < 0.05; ***p-value < 0.01, n.s. = not significant.

Raising the electricity meter above the most likely flood level significantly reduces the flood damage to home contents in the Var, and the West. The effect of the water level on the damage for respondents who implemented this measure is smaller compared to other respondents in the Ardennes. In the Var, the effect of the water level is higher when this measure is implemented, but the reducing effect of the measure itself means that even when the water level is high, the measure remains effective in...
reducing the damage to home contents. In the Var, this measure is less effective for respondents who live close to the source of the flood.

The damage reducing effect of raising the power sockets observed in the overall sample is driven by the Var and the Ardennes, but this measure is not effective in the Ardennes for people who live close by the river. Moreover, in the Var, the measure significantly compensates the effect of water levels on the damage to home contents.

Although anti-backflow valves were insignificant in the overall sample regression, this measure significantly reduces flood damage in the Ardennes and the Var, but is less effective in the Ardennes if flood depths are high. Sandbags effectively reduce the damage in the Ardennes, as a function of flood depths, while this measure is not significant in the other regional models.

Adapting the furniture in flood-prone parts of the home only reduces the damage in the Var for respondents who live farther than 100 meters away from the source of the flood. That measure is not effective in the Ardennes, where raising electrical appliances does reduce flood damage as a function of water depth.

Overall it is apparent from the regional models of flood damage to buildings and contents that none of the measures that involve using water-resistant materials significantly reduces damage in the West, where mainly coastal floods occur. These results imply the greater corrosiveness of saltwater compared with freshwater.

### 5.3.3 Assessment of the effectiveness and cost-effectiveness of the mitigation measures in reducing flood damage

Using the methodology described in Section 5.2.3 we calculated the average damage avoided per flood by effective mitigation measures (Table 5-5), the flood damage avoided over the life-time of a flood damage mitigation measure and their costs (Table 5-6), which are inputs for the cost-benefit analysis (Table 5-7).

Table 5-5 shows that the average effects of the mitigation measures vary considerably between regions and types of damage. Some measures, such as elevating the ground floor, appear to be very effective in reducing the damage to both the buildings and the home contents. Flood damage can be reduced by 1,000 to up to 6,500 euros. Using water-resistant materials can reduce damage to buildings up to about 8,200 euros. Raising the electricity meter reduces the damage to buildings by 4,700 euros, and the damage to home contents up to over 11,000 euros. Raising the power sockets
also significantly reduces the damage by up to 4,700 euros. Anti-backflow valves and elevating the boiler also substantially reduce the flood damage to buildings in the West up to about 9,000 euros, although these two measures have mixed results depending on the regions. Installing sandbags or other water barriers does not result in large damage savings, except for a small reduction in flood damage to home contents in the Ardennes. An explanation for the limited effectiveness of sandbags may be that they can overtop or collapse during high flood depths, which can cause substantial damage as other studies have shown (FEMA 2009; Kreibich et al., 2011, 2012). This finding may also reflect the strong correlation between the implementation of this measure with the variable living close by the source of flooding, which cannot be accounted for by an interaction variable because of the aforementioned problems with multi-collinearity. Raising electrical appliances reduced the damage to home contents in the overall sample and in the Ardennes by almost 1500 euros.

The results of the discounted life-time benefits of implementing effective flood damage mitigation measures are shown in Table 5-6 along with estimated total costs of
the measures. These cost values are approximations based on unit costs from US and British studies (ABI, 2003; FEMA, 2009; Aerts et al., 2013), which means that they provide a rough approximation of the cost of the mitigation measures. Most of these values are provided as ranges of costs because the actual costs of the implementation of the measures can vary depending on various factors such as the age, the state, and the type of homes in which the measure is installed. Following Table 5-6, a summary table (Table 5-7) provides the results of a qualitative ranking of the cost-effectiveness of the measures. Such a qualitative instead of a quantitative analysis is in order here, because the implied precision of the latter may be deceptive given the uncertainty of our cost-estimates. Measures are categorized as being cost-effective (++) if more than 75 per cent of the BC ratios are above 1, moderately cost-effective (+-) if between 25 per cent and 75 per cent of the BC ratios are above 1, and not cost-effective (–) if less than 25 per cent of the BC ratios are above 1.

Two of the eleven measures considered in this study, namely strengthening the foundations and using water-resistant materials for the walls, are not cost-effective. Installing sandbags, raising electrical appliances, and adapting the furniture are measures which can be cost-effective, but mostly in areas where flood probabilities are high. The reason is that life-time damage savings are high when floods occur frequently. Installing anti-backflow valves has mixed results. It can be cost-effective for damage to buildings even for low probability floods, but for damage to home contents it is a measure that is only cost-effective in areas with very high flood probabilities (1/1 year). A few measures are cost-effective, such as elevating the ground floor. Even when flood probabilities are low, discounted life-time damage savings of elevation are substantial (about 20,000 euros). It should be noted that elevation of homes is especially cost-effective when buildings are newly constructed, but not for existing buildings since elevating the latter is more expensive (Aerts et al., 2014). Using water-resistant materials for the floor, raising the electricity meter, the power sockets, and the boiler in the West are three measures, which are cost-effective for high-probability floods, and can be cost-effective for low-probability floods. These are relatively low-cost measures that can save large amounts of money during a flood (Table 5-6).
Table 5-6 Flood damage avoided to buildings and to home contents over the life-time of the mitigation measures.

<table>
<thead>
<tr>
<th>Measures (estimated lifetime) \ Regions</th>
<th>Benefits to buildings (in Euros)</th>
<th>Benefits to home contents (in Euros)</th>
<th>Costs of the measures (in Euros) (ABI, 2003; FEMA, 2009; Aerts et al., 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flood probability of 1/1 year All regions Ardennes Var West</td>
<td>Flood probability of 1/10 years All regions Ardennes Var West</td>
<td>Flood probability of 1/50 years All regions Ardennes Var West</td>
</tr>
<tr>
<td>Elevated ground floor (50 years)</td>
<td>99818 33655 109620</td>
<td>9982 3365 10962</td>
<td>996 67 2192</td>
</tr>
<tr>
<td>Floor made of water-resistant materials (50 years)</td>
<td>94285 6680</td>
<td>9428 668</td>
<td>1886 134</td>
</tr>
<tr>
<td>Raised electricity meter (50 years)</td>
<td>122208 162503</td>
<td>12221 16250</td>
<td>2444 3250</td>
</tr>
<tr>
<td>Raised power sockets (50 years)</td>
<td>93632 77390 27333 9363</td>
<td>7739 2733 1873</td>
<td>1544 543</td>
</tr>
<tr>
<td>Anti-backflow valves (10 years)</td>
<td>570 71626 57 7163</td>
<td>7163 11</td>
<td>1433 1750</td>
</tr>
<tr>
<td>Elevated boiler (50 years)</td>
<td>187364 18736</td>
<td>18736</td>
<td>3747</td>
</tr>
<tr>
<td>Floor made of water-resistant materials (50 years)</td>
<td>7786 40611</td>
<td>779 4061 356</td>
<td>812 812</td>
</tr>
<tr>
<td>Raised electricity meter (50 years)</td>
<td>63970 222133 84858 6397</td>
<td>22339 8486 1279</td>
<td>4463 1697</td>
</tr>
<tr>
<td>Raised power sockets (50 years)</td>
<td>31599 47646 3160 6689</td>
<td>3160 4765 632</td>
<td>1338 953</td>
</tr>
<tr>
<td>Anti-backflow valves (10 years)</td>
<td>9170 3189</td>
<td>917 319</td>
<td>183 64</td>
</tr>
<tr>
<td>Sandbags or water barriers (50 years)</td>
<td>27252 29149</td>
<td>2725 2915</td>
<td>545 583</td>
</tr>
<tr>
<td>Raised electrical appliances (50 years)</td>
<td>4138 414</td>
<td>83</td>
<td>No reference found</td>
</tr>
</tbody>
</table>
5.4 Discussion of the results and main conclusions

Flood-proofing of homes has often been proposed as an effective strategy to limit future increases in flood damage that may be caused by climate change. An obstacle for the design of policies to flood-proof buildings is that few empirical studies have estimated the effectiveness of household flood damage mitigation measures. As a result, little is known about what specific measures are effective in reducing losses during floods, and about how much damage can be avoided by implementing them. Moreover, few studies have examined the cost-effectiveness of installing flood damage mitigation measures, while such information can be important for prioritizing measures that have a good economic return.

A novelty of our study is the application of regressions models to estimate the independent effect of flood damage avoided for specific mitigation measures in regions with different flood characteristics, and the use of these estimates in an analysis that examines the cost-effectiveness of these measures. To our knowledge this the first study that examines the (cost-)effectiveness of flood risk mitigation measures in

Table 5-7 Summary of the cost-benefit analysis of the mitigation measures for different flood probabilities.

<table>
<thead>
<tr>
<th>Measures \ Flood probability</th>
<th>1/1 year</th>
<th>1/10 years</th>
<th>1/50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevated ground floor (50 years)</td>
<td>++ for buildings, + for contents; During construction: ++</td>
<td>++ for buildings, + for contents; During construction: ++</td>
<td>++ for buildings, + for contents; During construction: ++</td>
</tr>
<tr>
<td>Foundations strengthened (50 years)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Walls and equipment made of water-resistant materials (50 years)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Floor made of water-resistant materials (50 years)</td>
<td>++</td>
<td>++ for buildings + for contents</td>
<td>–</td>
</tr>
<tr>
<td>Raised electricity meter (50 years)</td>
<td>++</td>
<td>++ for buildings + for contents</td>
<td>–</td>
</tr>
<tr>
<td>Raised power sockets (50 years)</td>
<td>++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Anti-backflow valves (10 years)</td>
<td>++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Elevated boiler (50 years)</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Sandbags or water barriers (50 years)</td>
<td>++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Raised electrical appliances (50 years)</td>
<td>++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Furniture adapted (10 years)*</td>
<td>++</td>
<td>++</td>
<td>–</td>
</tr>
</tbody>
</table>

Notes: ++: cost-effective; +:: moderately cost-effective; –: not cost-effective

* The estimation of the cost-effectiveness of this measure is based on expert judgment.
Effectiveness of flood damage mitigation measures

France. Our methodological approach of using survey data about individual flood preparation activities and flood damage experience and of estimating reduced flood damage and costs and benefits of flood risk mitigation is, in principle, generic and transferable to other regions.

Previous studies have assessed the effectiveness of private flood damage mitigation measures with a simple comparison of means of flood damage suffered by people who have, or have not, implemented such measures. The application of regression models in this chapter to estimate damage savings by mitigation allows for controlling for the effects of the water height and other variables on flood damage, and, therefore, can more accurately assess the independent effectiveness of specific flood damage mitigation measures. For this purpose a unique data set was collected by surveying 885 households about their flood preparedness and flood experiences in three flood-prone regions in France, including 530 households who have previously been flooded in their homes. Regression models were estimated separately for the damage to buildings and the damage to home contents, and for the different regions in which the survey was conducted. To control for the effectiveness of the measures in reducing the damage, variables of the mitigation measures were included in the models, along with variables of the water depth and the characteristics of the home. Moreover, the survey was conducted such that it allowed for evaluating individual mitigation measures rather than a few groups of measures. It was, therefore, possible to assess the effectiveness and cost-effectiveness of 11 specific flood damage mitigation measures. Four main conclusions can be drawn from this study.

First, using regression analysis results in improved estimates of the effectiveness of mitigation measures compared with a comparison of mean damage used by earlier studies. For example, it is clear from the results that the water depth and the distance to the source of the flood are important variables that explain a large part of the variations in the recorded flood damage, and in several instances interact significantly with the effects of the mitigation measures. Moreover, the regression models show that a variety of mitigation measures have a significant influence on flood damage. When the effects of these variables on the damage are not controlled for, then the damage reduced by a specific mitigation measures may not correspond to the independent effect the measure has on the damage. When the results in Table 5-2 and Table 5-3 are compared, it is apparent that the mean damage always results in greater damage avoidance than the independent effects of damage saved per measure resulting from the regression models.

Second, this study has provided empirical insights showing that some mitigation measures can substantially reduce flood damage. This is important information for
the design of flood risk management policy, and shows that stimulating the adoption of flood damage mitigation measures, for example through building codes, can provide substantial complementary benefits of reduced flood risk to traditional flood protection infrastructure.

Third, the effectiveness of the mitigation measures is very regional-dependent. This can be explained by the different characteristics of the flood hazard in our sample areas that experience either slow onset river flooding (the Ardennes) or more rapid flash flooding (the Var) or coastal flooding (the West). Overall these findings imply that care should be taken with designing flood risk management policies, such as building codes, since measures that work well in one region may not be effective in another region that faces a different kind of flood hazard. Nevertheless, some measures appear to be effective in all of the regions considered here.

Fourth, the cost-efficiency of the flood damage mitigation measures depends strongly on the flood probability faced by households. Therefore there is a high degree of variation in the efficiency and effectiveness of the measures in each region, depending on its flood hazard characteristics. A high flood frequency is required before costly investments in the flood-proofing of homes pays off. This suggests that strategies of reducing flood risks through flood-proofing of buildings become more economically attractive if climate change increases flood frequencies, as has been projected for many regions worldwide (IPCC, 2012). Most of the flood damage mitigation measures are cost-effective in areas where flood probabilities are larger than 1/10 year. Nevertheless, some measures have been identified that can be cost-effective in areas with lower flood frequencies (1-in-50 year flood probability).

It can be concluded that policy makers should not only advise households to implement mitigation measures, but they should also provide advice on which measures to install. The provision of such information could ensure that households take measures that are effective and efficient in the region in which they live and for the type and frequency of floods they face. Flood management strategies which focus on the household level should be fitted to the local conditions. Further research on the costs and the (cost-)effectiveness of individual mitigation measures in regions subject to different types of floods could provide improved knowledge to policy makers around the world.
6 Synthesis and Conclusion

6.1 Main research themes and objectives

This thesis focused on four main research themes, which were introduced in Section 1.1.

The first theme was an examination of the French natural disaster insurance system — the CatNat system — and its links with PPRs. The CatNat system and the PPRs were created with the aim to provide households with financial coverage for flood risk, while limiting flood damage in flood-prone areas. There have been calls to improve the operation of this system and to offer additional incentives for households and communities to implement flood damage mitigation measures, which provided a rationale for researching this theme.

Second, an emerging literature exists on the factors that influence households’ decisions as to whether to implement flood damage mitigation measures, such as individual risk perceptions, coping appraisals, or flood experience. However, the empirical basis for understanding flood preparedness decisions is small; and, researchers have suggested that it would be useful to study further these factors across different regions, and for various local characteristics of flooding, such as was done in this thesis. The theoretical basis for this analysis is based on an extended version of PMT.

The third theme focused on providing additional insights into the capacity of semi-structural (i.e. flood damage mitigation) and non-structural (i.e. spatial zoning) measures to decrease flood risk beyond the local level, both now, and in the future. This was motivated by the emerging literature on flood risk management, which proposes that combinations of flood protection and damage mitigation may provide an effective mix to cope with future flood risk.

The fourth theme was about improving understanding of the effectiveness of private flood damage mitigation measures. The few existing empirical analyses of flood damage avoided by private mitigation measures found that the savings can be large. However, an obstacle for the design of policies is that little is known about which specific measures are effective in reducing flood losses, and about how much damage can be avoided by implementing them. Moreover, few studies have examined the
cost-effectiveness of installing flood damage mitigation measures, while such information could be important for prioritizing measures that have a good economic return. This thesis provided insights into the cost-effectiveness of private flood damage mitigation measures in different flood-prone regions.

These themes were examined in this thesis according to the two main research objectives to (a) improve understanding of the implementation of flood damage mitigation measures by households in France and the factors that influence individual decisions to prepare for flooding, and (b) obtain insight into the (cost-) effectiveness of flood damage mitigation measures in reducing flood losses. These two objectives were divided into four research questions of which the main results will be discussed in the next section. Research questions 1 and 2 provided answers for objective 1; and research questions 3 and 4 provided answers for objective 2.

6.2 Main results per research question

1. How does the French CatNat system influence households to implement flood damage mitigation measures, and what can be done to improve the incentives with regard to risk reduction?

This research question was addressed in Chapter 2, which presented results from a literature review and a mail survey of French households about their flood preparedness. The analysis in Chapter 2 showed that the CatNat system and linked PPR regulations provide a strong financial security to households. Moreover, the implementation rates of some mitigation measures by French households living in flood-prone areas are high. The CatNat system provides reasonably good financial security for households as 80 per cent to 90 per cent of the requests for natural disaster decrees which enable damage reimbursement have been granted by the government. However, the drawback to this high financial security provided by the CatNat system is that it can decrease the willingness of homeowners to take flood protection measures. Chapter 2 showed that PPRs can, in some cases, limit new constructions in flood-prone areas, and limit, or avoid, flood damage. However, these results are mixed; and, the results from the existing analyses of the effectiveness of PPRs appear to be anecdotic or inconclusive. The results of the survey presented in Chapter 2 show that only about 2 per cent of the households implemented their mitigation measures after receiving incentives from PPRs. In general, the results also show that overall levels of flood preparedness can be improved; although, the current regulations and insurance incentives play only a minor role in households’ decisions to prepare for flooding.
Given the projected increase in future flood risk, the question arises as to whether the current CatNat system can effectively accommodate these risks (e.g. through the stimulation of damage mitigation by households). A variety of concrete improvements of the CatNat system have been proposed in Chapter 2, aimed at stimulating the undertaking of damage mitigation measures and, thereby, increase the resilience of France to flooding. Among the suggestions for improvements are differentiating insurance premiums, as well as deductibles, according to flood risk; increasing the incentives for PPR applications and approvals; increasing the effectiveness of PPRs; and, improving the oversight of the implementation of mitigation measures.

2. What factors explain household decisions as to whether to prepare for flooding? In particular, to what extent does PMT explain households’ flood preparedness decisions, and, what important elements need to be added to that theory?

This research question was answered in Chapter 3 by applying regression models that explained household flood preparedness decisions with explanatory variables, based on an extended version of the PMT. For this analysis, data was collected by surveying almost 900 households in three flood-prone areas in France about their flood preparedness decisions and variables of influence on flood preparedness. A starting point for this research was the basic version of PMT, which explains households’ decisions to prepare for risk using threat appraisals, which are individual risk perceptions, and coping appraisals that capture individual attitudes toward specific protection measures. Several studies show that PMT has explained household flood preparedness decisions in a variety of settings (Chapter 3). Nevertheless, a literature review shows that several important elements are missing from the basic version of PMT, which are added in the analysis in Chapter 3: namely, individual flood experiences, risk attitudes, social networks, social norms, local flood risk management policies and incentives, as well as socioeconomic characteristics of individuals.

Regression models of the extended version of PMT indicate that threat appraisals have only minor effects on flood damage mitigation behavior, while coping appraisals have a larger influence, especially on the implementation of structural measures and households’ intentions to take additional measures. In particular, the numbers of installed structural and avoidance measures, as well as the willingness to take additional measures, are positively related with individuals' perceived ability to implement these mitigation measures (self-efficacy). Individuals who perceived the mitigation measures as time consuming to install were less likely to take these measures, and fewer structural measures were utilized by individuals who perceived these as being costly (response costs). Individuals who expected that flood damage mitigation measures are effective in reducing flood damage have higher intentions to imple-
ment additional measures (response-efficacy). In addition, the extension of PMT appears to be useful, since flood experience and local flood management policies and incentives are shown to be influential in households’ mitigation decisions. The results of the socioeconomic characteristics of respondents were mixed, while differences in the factors of influence on households’ mitigation behavior can be observed between the three case study areas and the different categories of mitigation measures. These differences in results may be related to the particular types of floods and the frequency and severity of flooding, which have been experienced in these areas. Overall, the statistically significant effects of the variables of flood risk management policies and incentives are encouraging, as they show that the provision of information and incentives can increase the number of flood damage mitigation measures that households utilize.

3. **What methodology can be developed to assess the effectiveness of spatial zoning and flood damage mitigation measures in reducing current and future flood damage and risk in the Meuse river basin?**

In order to answer this research question, the Damage Scanner model was applied to simulate potential flood risk. This model used land-use and inundation maps for the years 2000 and 2030, as input to simulate both current and future risk (Chapter 4). This model was used to assess the sensitivity of riverine flood risk in the Meuse river basin to both changes in land use and climate. Based on simulations of the current and future risk, the potential of different adaptation strategies for flood risk reduction was estimated at the regional scale. For this purpose, spatial zoning and flood damage mitigation measures were included in the flood damage model. In particular, the impact of spatial zoning on flood risk was estimated by modifying the 2030 land-use maps according to a planned spatial zoning project. This had the effect of reducing economic values exposed to flooding in the model, and, hence, lowers projected flood risk. Flood damage mitigation measures were included in the model by adjusting stage damage curves of the flood damage model, which had the effect that estimated flood damage declines for a given level of exposure and hazard (potential flood depth). The model results suggest that, for the Dutch region of the Meuse, without implementation of adaptation strategies, annual flood risk may increase by up to 185 per cent by 2030, as compared with 2000, as a result of combined land-use and climate changes. The independent contributions of climate change and land-use change to the simulated increase are 108 per cent and 37 per cent, respectively. The risk-reduction capacity of the implementation of spatial zoning measures, which are intended to limit and regulate developments in flood-prone areas, is between 25 per cent and 45 per cent in the Netherlands. The modeling framework was used to estimate the potential impact of three mitigation strategies—dry-proofing, wet-proofing,
and a combination of dry- and wet-proofing—in residential areas. The results indicate that these strategies have a risk-reduction capacity of between 21 per cent - 40 per cent, depending on their rate of implementation in the Netherlands. Combining spatial zoning and mitigation measures could reduce the total projected increase in future flood risk by up to 60 per cent in the Netherlands.

For France, potential risk reductions for flood-proofing and spatial planning are, of course, regionally dependent; however, the effectiveness of these measures in reducing risk is broadly similar between the Netherlands and France. Dry-proofing can reduce flood risk by up to 30 per cent, and wet-proofing up to 20 per cent, in France. The highest risk reductions can be obtained in Belgium, where flood-proofing can reduce risk by more than 40 per cent in some areas. Several policy implications of these results are discussed in Chapter 4, including incentives for the adoption of flood damage mitigation measures by means of building code requirements, financial incentives through insurance, and information provision to households.

4. What process should be used to assess the cost-effectiveness of individual mitigation measures to reduce flood risk for homeowners? What measures should be prioritized that homeowners can implement for reducing flood risk to their properties?

Previous studies have assessed the effectiveness of private flood damage mitigation measures with a simple comparison of flood damage suffered by people who have, and have not, implemented such measures. Chapter 5 applied regression models to estimate the damage avoided by mitigation measures. Regression models allow for controlling the effects of the water height and other variables on flood damage, and therefore, can more accurately assess the independent effectiveness of specific flood damage mitigation measures. For this purpose, a data set was collected by surveying 885 households about their flood preparedness and flood experiences in three flood-prone regions in France (see Table 1-1), including 530 households who had previously been flooded in their homes. Regression models were estimated separately for the damage to buildings, the damage to home contents, and the different regions in which the survey was conducted. Moreover, the survey was conducted such that it allowed for evaluating individual mitigation measures, rather than a few groups of measures. The estimated damage savings of mitigation were used in cost-benefit analyses, which examined the (cost-) effectiveness of 11 individual mitigation measures, rather than a few groups of measures, as previous studies have done.

Four main conclusions were drawn from the study. First, using regression analysis resulted in improved estimates of the effectiveness of mitigation measures versus a comparison of mean damage used by earlier studies, which provides relevant insights
for prioritizing measures. Moreover, the regression models exhibited that a variety of factors have a significant influence on flood damage. If the effects of these variables on the damage are not controlled for, then the damage reduced by a specific mitigation measure may not correspond to the independent effect the measure has on the damage. Second, this study provided empirical insights showing that some mitigation measures can substantially reduce flood damage. Third, the effectiveness of the mitigation measures is regional-dependent; although, some measures appear to be effective in all of the regions considered in the study. This is explained by the different characteristics of the flood hazard in our sample areas, which experience slow onset river flooding (the Ardennes), more rapid flash flooding (the Var), or coastal flooding (the West). Fourth, the cost-effectiveness of the flood damage mitigation measures depends strongly on the flood probability that households confront. A high flood frequency is required before costly investments in the flood-proofing of homes makes financial sense. For example, installing sandbags, raising electrical appliances, and adapting the furniture can be cost-effective measures, but mostly in areas where flood probabilities are high. This suggests that strategies of reducing flood risks through flood-proofing of buildings will become more economically attractive if climate change increases flood frequencies. Most of the flood damage mitigation measures are cost-effective in areas where flood probabilities are larger than 1/10 years. Nevertheless, some measures have been identified (i.e. elevating homes during construction of a building) that can be cost-effective in areas with lower flood frequencies, namely for a flood probability of 1/50 years.

6.3 Recommendations for policymakers

The analyses in Chapters 4 and 5 showed that zoning regulations and building level damage mitigation measures can be effective in reducing flood risk. Especially with climate change projected to increase, the frequency and severity of flooding in the future, such measures may be an important element of flood risk management strategies to adapt to increasing risk. A challenge for policymakers is to enable the implementation of flood damage mitigation measures, because research has shown that many people in floodplains do not take such measures, even when they are cost-effective. This sub-section discusses several recommendations for policymakers to help floodplain inhabitants better prepare for future flood events.

Improvement of the French CatNat system and its incentives for risk reduction

Several improvements of the CatNat system have been proposed in Chapter 2 to stimulate the undertaking of damage mitigation measures and increase the resilience
of France to flooding. These suggestions include providing stronger incentives for PPR applications and approvals, increasing the effectiveness of PPRs, and improving oversight of the implementation of mitigation measures. In particular, results from the survey show that certain mitigation measures are only rarely implemented by households, and most households do not receive incentives from their insurer to undertake mitigation measures. These findings could be remedied through two means. First, adequate and additional information could be provided about the risk faced by policyholders and the mitigation measures that are prescribed by PPRs and, in general, which are at the disposal of households. Second, insurers have some means to encourage policyholder compliance with the community’s PPR, for after a natural disaster has been declared, insurers can decline compensation if, five years after its approval, there is non-compliance with the PPRs mitigation prescriptions. However, this derogation has seldom been applied. For consumer and political interests, it may be more desirable to actively stimulate mitigation “ex ante” floods, instead of denying compensation “ex post” flood events.

In addition to the diversity of suggestions for improvement of the CatNat system provided in Chapter 2, a broader modification of this scheme could be envisioned to increase the incentives for damage mitigation by households ex ante floods. CatNat currently charges fixed premiums, which are advantageous in that they provide high financial security for households living in flood-prone areas. However, they also have the disadvantage that the amount of natural disaster premiums paid are not associated with their actual flood risk. This limits incentives for mitigation, given that insurers cannot use financial incentives to stimulate households to take risk-reducing measures. In order to encourage damage mitigation by households, insurers could charge risk-based premiums that provide policyholders with a price signal of the flood risk they face. Risk-based premiums could limit the incentives to settle in flood-prone areas, because the awareness of the risk, and the costs of living there, increase. Also, risk-based premiums could provide a direct monetary benefit to policyholders who undertake mitigation measures, in terms of a premium reduction that would reflect the reduction of risk induced by mitigation. Nevertheless, it should be realized that introducing risk-based premiums for households could be complicated in practice because of the need for detailed, spatially-differentiated information on flood risk, and also, because it could conflict with the solidarity principle.

Provision of information and subsidies to households

The empirical analyses in Chapter 3 of factors of influence on flood preparedness decisions of households resulted in two main recommendations for flood risk management policies. First, the important role of coping appraisals in household deci-
sions to invest in flood risk reduction, suggests that the provision of information on flood damage mitigation measures could be improved, in order to better prepare households for flooding. Improving the provision of information by the government, municipalities, and insurers could further encourage households to prepare for floods. Campaigns could provide information about the types of measures that are available to limit flood risk, the ways they can be implemented, and the evidence of their effectiveness. This could increase households coping appraisals, thereby improving flood preparedness.

Second, improved financial incentives could be provided to households who invest in costly structural measures, such as flood-proofing of buildings with water-resistant materials. Perceived high cost appears to be an obstacle for the actual implementation of structural measures. Therefore, additional subsidies (or other financial incentives, such as insurance premium discounts) could be granted for the implementation of expensive (but cost-effective) mitigation measures. This is supported by the analysis in Chapter 2 of the functioning of the Barnier fund that can subsidize flood risk-reduction activities in France. The survey results presented in that same chapter show that subsidies were not used by households to finance the implementation of their mitigation measures, even though the costs of the measures appear to be a factor influencing the decision of whether to implement structural risk-reduction and damage avoidance measures. In order to increase the use of subsidies by households, the allocation of the funds could be made less dependent on PPR applications and approvals, and instead, could provide financial resources on the basis of the flood risk level and the mitigation measures to be taken by vulnerable households. Also, households could be provided with information on available subsidies and efficient risk-reducing measures. It should be noted that increased availability of subsidies, could result in an increased demand for grant money, which would require an increase in the funds’ financial capacity.

**Flood management policies fitted to the local conditions**

Since some mitigation measures can be (cost-) effective in reducing flood damage, it can be concluded that stimulating the adoption of flood damage mitigation measures could result in substantial reduction of flood losses. However, Chapter 5 has shown that the effectiveness of the mitigation measures is highly regional-dependent, which implies that care should be taken with designing flood risk management policies, such as building codes, since measures that work well in one region may not be effective in another that faces a different kind of flood hazard. In addition, the cost-effectiveness of the flood damage mitigation measures depends strongly on the flood probability faced by households. A high flood frequency is required before costly
investments in flood-proofing of homes prove beneficial. Therefore, policymakers should not only advise households to implement mitigation measures, but they should also provide advice on which measures to install in which specific areas. The provision of such information could ensure that households take measures that are effective and efficient in the region in which they live, and for the type and frequency of floods they encounter. Flood management strategies that focus on the household level, should be fitted to the local conditions.

6.4 Recommendations for future research

This thesis aimed to fill gaps in knowledge about flood preparedness decisions by households and the effectiveness of flood damage mitigation measures, thereby, contributing to an emerging literature on these topics.

Chapters 2 and 3 discussed a variety of incentives that policymakers and insurers can use to stimulate households to implement flood risk mitigation measures, such as risk-based premiums and subsidies. Future research could empirically examine the effectiveness of such financial incentives in encouraging mitigation behavior. Moreover, future research in other flood-prone areas could analyze whether similar factors influence households’ mitigation behavior, as this thesis found for France. This is of special interest given the important role that local risk management policies and cultures are likely to play in flood preparedness decisions.

Furthermore, an important finding of the empirical studies in this thesis is that flood damage mitigation measures can be (cost-) effective in reducing flood damage, at the regional level as well as at the household level. A limitation in drawing general lessons from these findings is that these results were obtained from particular case study areas. Future research could aim at providing local, regional, or basin-level data on the damage- and risk-reduction capacity of the flood damage mitigation measures and adaptation strategies in other areas. Expanding the knowledge base about which measures are effective to cope with different types of flood events, can provide valuable input for policymakers, and stimulate discussions on the benefits of employing and encouraging the implementation of risk-reduction strategies.

In terms of future research to estimate flood risk, and to model the effect of flood preparedness, many uncertainties exist. The modelling framework used in this study is relatively simple, but it does allow for assessing the sensitivity of flood risk to climate and land-use change, and to several adaptation options, at a large geographical scale. Furthermore, as stated in chapter 4, the land-use maps are not precise at the
local level and further research would be needed to increase the precision of the land-use maps and the assets that are at risk from flooding (houses, infrastructure). Additional modelling of the risk and damage on a wider scale (e.g. whole-basin scale) could also contribute to the basin wide discussion on the effectiveness of – local household mitigation measures, spatial zoning, and the scale at which these adaptation strategies should be used. The spatial zoning measure as applied in this study assumes that although the demand for urban developments will remain, the new buildings will be built outside of the flood-prone area since new buildings within it are not allowed. This assumption can lead to an underestimation of urban development in flood-prone areas in the model. Therefore, additional modelling focused on the allocation of new construction areas under spatial zoning restrictions will have to be conducted to take into account the remaining demand for urban developments. In addition, research and modelling with methods that allow for more precision on the degree of implementation of the mitigation measures at the town, region, or basin scale could further increase the precision of such a model. Methods to improve these results could include the gathering of data via workshops, interviews, or surveys.

Flood preparedness is often assumed to be constant in flood damage models, such as the model applied to the Meuse in Chapter 4, and future research could focus on integrating households' behavior in flood risk assessments. Even more, there is need for further research on the costs and the (cost-) effectiveness of individual mitigation measures, such as the 11 measures studied in this thesis, as well as others, in regions subject to different types of floods. Modelling methods such as agent-based modelling could prove to be useful in representing the behaviour and preparedness of households.

Finally, the mitigation factors used in this research were derived from the literature on the effectiveness of mitigation measures during past floods. Even though the differences in results with Kreibich and Thieken (2009) can be explained by the differences in inundation depths, further research on the subject of the effectiveness of mitigation measures in past and modelled floods could increase the precision of the model and the value of the results for decision makers. Including efficiency aspects of the measures – with the addition of knowledge such as the cost and the difficulty of implementing the measures – could also provide valuable input for decision makers.
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References


Flood damage mitigation investments


References


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Flood damage mitigation investments


Olfert, A., Schanze, J., 2008. New approaches to ex-post evaluation of risk reduction measures: The example of flood proofing in Dresden, Germany. In: Flood Risk Management: Research and
References


References


Flood damage mitigation investments


## Appendix A

### Table A-1 Summary of the suggestions for improvements and their main implications.

<table>
<thead>
<tr>
<th>Suggestions for improving the CatNat system</th>
<th>Main economic, social, and political implications</th>
</tr>
</thead>
</table>
| *Apply the derogation to compensate in case of non-compliance with the PPR and provide information on the risk and the prescribed and available mitigation measures* | – Encourages the implementation of mitigation measures, including the measures required by the PPRs;  
– Reduces financial security of households who may be declined compensation of damage;  
– Politically it may be difficult to decline compensation after a disaster. |

**Increase the effectiveness of PPRs by:**  
– Making the PPR mitigation measures more adequate for local needs;  
– Standardizing the hazard definitions and procedures of PPRs;  
– Increasing the capacity of communities to implement PPRs;  
– Creating rules to help and monitor the realization and implementation of PPRs;  
– Providing information to households on the cost, complexity, implementation, and cost-effectiveness of mitigation measures;  
– Creating incentives for the revision of PPRs;  
– Increasing knowledge on cost-efficient measures.  

<table>
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– Providing information to households on the cost, complexity, implementation, and cost-effectiveness of mitigation measures;  
– Creating incentives for the revision of PPRs;  
– Increasing knowledge on cost-efficient measures. |  

**Increase the production of PPRs for communities at risk of flooding by:**  
– Broadening the applicability of the deductibles’ adjustment in the absence of a PPR;  
– Calculate deductibles (and the adjustment) based on the natural disaster risk;  
– Ending the adjustment (increase) of deductibles only after the full approval or implementation of the PPR.  

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</thead>
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– Ending the adjustment (increase) of deductibles only after the full approval or implementation of the PPR. |  

**Facilitate financing of mitigation measures by:**  
– Increasing efficiency of the Barnier Fund by making funding less dependent on PPR applications and approvals and dependent on the flood risk;  
– Providing loans for mitigation investments by households;  
– Government subsidies for mitigation for poor households in the form of income tax reductions, income support, or vouchers.  

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– Increasing efficiency of the Barnier Fund by making funding less dependent on PPR applications and approvals and dependent on the flood risk;  
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– Government subsidies for mitigation for poor households in the form of income tax reductions, income support, or vouchers. |  

**Charge risk-based insurance premiums to stimulate mitigation**  
– Risk decreases because of increased implementation of voluntary mitigation measures;  
– Risk-based premiums raise risk awareness and create incentives to settle in low-risk areas;  
– Risk-based reinsurance premiums incentivize insurers to stimulate policyholders to take mitigation measures and not settle in high-risk areas;  
– Risk-based premiums conflict with national solidarity.  

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– Risk-based premiums conflict with national solidarity. |
Appendix B

B1 Factors of influence on the implementation of mitigation measures by households

Reviews of the literature on flood risk perceptions, communication and flood preparedness by Bubeck et al. (2012b) and Kellens et al. (2012) show that a variety of approaches have been taken to model individual behaviour. These reviews propose that ‘Protection Motivation Theory’ (PMT) provides a useful model for describing how individuals prepare for flood events, although PMT does not provide a complete picture of behaviour. PMT postulates that protection behaviour is driven by two main components: namely, threat appraisal and coping appraisal. PMT predicts that individuals will protect themselves against a particular hazard if they think that the threat of the hazard that they face is high (high ‘threat appraisal’), and if they perceive that the protective measures available are effective, easy, and not too costly to implement (high ‘coping appraisal’). Figure 3-1 shows these two components and their sub-components. Threat appraisal is defined as the perception by individuals of the hazard, which can be subdivided into perceptions of the threat’s likelihood of occurrence and of its consequences. Grothmann and Reusswig (2006) extend the traditional PMT framework by including the fear or worry about floods, which is related to threat appraisal. It has been shown that such emotion-related feelings towards risk can have an important influence on decision making under risk (Loewenstein et al., 2001). Coping appraisal concerns the attitudes that individuals have towards the available measures to cope with the threat. Chapter 3 shows that coping appraisal consists of three sub-components: namely, perceived response-efficacy; perceived self-efficacy; and perceived response-costs (Grothmann and Reusswig, 2006). Perceived response-efficacy is the perceived effectiveness and usefulness of the measures in reducing the damage. Perceived self-efficacy is the individual’s perception of his own capacity to implement the measures. Perceived response-costs are the individual’s expectations of the financial costs of the measures, but also of the time and effort needed to implement them, their complexity, and their impact on the appearance or the value of the home.

It has been shown that threat appraisal and coping appraisal are two important components that influence households to undertake protective measures (Bubeck et al., 2012b; Grothmann and Reusswig, 2006). However, when testing for the effect of
threat appraisal on the implementation of mitigation measures in cross-sectional surveys, it may also be found that this relation is weak or negative (Bubeck et al., 2012b). An explanation for this weak relation is that, in such surveys, the measurements of the risk perceptions are done after the mitigation measures have been implemented by the individuals, which causes a decline in risk perceptions (Weinstein and Nicolich, 1993; Bubeck and Botzen, 2013).

In addition to the components of PMT, in this study we aim to test an extended PMT framework, including other factors that can be important in determining the protective behaviour of individuals. These factors have been identified by means of a literature review and classified in five main categories which are shown in Figure 3-1. The results of the literature review are summarized in Table B-1, which shows the variables of influence on individual preparedness for risk that have been studied, the direction of the effects that have been observed in each study (i.e. a positive, negative, or no significant effect, indicated by “+”, “-“, or “0”, respectively), and whether or not the variables concerned have been measured in the French household survey.

19. In order to provide a comprehensive literature review, the selection of articles was conducted in a systematic way by entering the following words and combinations of words in the ISI web of knowledge: flood risk mitigation, flood protection, flood risk mitigation households, flood hazard behaviour, flood risk reduction, flood prevention, protection motivation theory flood, protection motivation theory disaster, flood preparedness, factors disaster preparedness, flood precautionary measures, flood risk attitude, flood risk attitude households, flood risk communication mitigation, flood risk mitigation incentive.
### Table B-1 Review of factors that influence the mitigation behaviour of households.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Effect</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threat appraisals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk perception</td>
<td>+/-0</td>
<td>Botzen et al., 2009b (+); Lindell and Hwang, 2008 (+); Miceli et al., 2008 (+); Neuwirth et al., 2000 (+); Sattler et al., 2000 (+); Soane et al., 2010 (+); Tekeli-Yesil et al., 2010a (+); Zaleskiewicz et al., 2002 (+); Weiss et al., 2011 (+/-); Kim and Kang, 2010 (+/0); Lindell and Perry, 2000 (+/0); Mileti and Peek, 2000 (+/0); Takao et al., 2004 (owners + / all 0); Karanci et al., 2005 (0); Laska, 1990 (0); Paton et al., 2006 (0); Sjöberg, 1999 (0);</td>
</tr>
<tr>
<td>Damage perception</td>
<td>+0</td>
<td>Botzen et al., 2009b (+); Floyd et al., 2000 (+); Lin et al., 2008 (+); Mclvor and Paton, 2007 (+); Milne et al., 2000 (+); Sjöberg, 1999 (+); Tekeli-Yesil et al., 2010a (+); Grothmann and Reusswig, 2006 (+/0); Lindell and Perry, 2000 (+/0); Karanci et al., 2005 (0); Terpstra, 2011 (0); Zaalberg et al., 2009 (0);</td>
</tr>
<tr>
<td>Probability perception</td>
<td>+/-0</td>
<td>Botzen et al., 2009b (+); Harries, 2012 (+); Lindell and Perry, 2000 (+); Terpstra, 2011 (+); Zaleskiewicz et al., 2002 (+); Lin et al., 2008 (-); Grothmann and Reusswig, 2006 (+/0); Sjöberg, 1999 (0);</td>
</tr>
<tr>
<td>Underestimating or ignoring</td>
<td>-</td>
<td>Kureuther, 2006; Tekeli-Yesil et al., 2010b (due to multiple risks);</td>
</tr>
<tr>
<td>probabilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainties in probability</td>
<td>+/-0</td>
<td>Defra, 2008 (+); Floyd et al., 2000 (+); Milne et al., 2000 (+); Zaalberg et al., 2009 (+); Harries, 2008 (+/-); Brilly and Polić, 2005 (0);</td>
</tr>
<tr>
<td>Vulnerability perception</td>
<td>+/-0</td>
<td>Botzen et al., 2009b; Botzen and Van den Bergh, 2012; Kreibich, 2011; Lindell and Perry, 2000;</td>
</tr>
<tr>
<td>Affect the quality of life</td>
<td>+</td>
<td>Botzen et al., 2010; Knocke and Kolivras, 2007; Lin et al., 2008;</td>
</tr>
<tr>
<td>Perceived risk for life</td>
<td>+</td>
<td>Knocke and Kolivras, 2007; Lin et al., 2008;</td>
</tr>
<tr>
<td>Perceived severity</td>
<td>+/-0</td>
<td>Neuwirth et al., 2000 (+); Ozdemir and Yilmaz, 2011 (+/0);</td>
</tr>
<tr>
<td>Social risk perception (for others)</td>
<td>+/-0</td>
<td>Lin et al., 2008;</td>
</tr>
<tr>
<td>Knowledge of (flood) hazard(s) and risk</td>
<td>+/-0</td>
<td>Lindell and Perry, 2000 (+); Mishra and Saur, 2012 (+); Paton et al., 2006 (frequency of discourse on risk +); Pynn and Ljung, 1999 (+); Tekeli-Yesil et al., 2010a (+); Botzen et al., 2009b (-); Ozdemir and Yilmaz, 2011 (-/0);</td>
</tr>
<tr>
<td>Lack of knowledge of the hazard and risk</td>
<td>+/-0</td>
<td>Pynn and Ljung, 1999 (-); Weiss et al., 2011 (+/-);</td>
</tr>
<tr>
<td>Perception</td>
<td>Rating</td>
<td>References</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Knowledge of protection</strong></td>
<td>+</td>
<td>Brilly and Polic, 2005; Lin et al., 2008; Lindell and Perry, 2000; Mishra and Suar, 2012; Tekeli-Yesil et al., 2010a; √ Thieken et al., 2007;</td>
</tr>
<tr>
<td><strong>Never offered / no knowledge of insurance or of effective, applicable protection</strong></td>
<td>-/0</td>
<td>Defra, 2008; Pynn and Ljung, 1999; Tekeli-Yesil et al., 2010b; Zaleskiewicz et al., 2002; Lindell and Perry, 2000; -/0;</td>
</tr>
<tr>
<td><strong>Fear or worry that a flood / event could occur, and the damage it could provoke</strong></td>
<td>+/-/0</td>
<td>Karanci et al., 2005; Milne et al., 2000; Pynn and Ljung, 1999; Sattler et al., 2000; Siegrist and Gutscher, 2008; Sjöberg, 1999; Takao et al., 2004; Terpstra, 2011 (dread +); Zhai et al., 2006; Lin et al., 2008 (dread +, worry -); Weiss et al., 2011; Lindell and Perry, 2000 (+/0); Zaleskiewicz et al., 2002 (dread +/-/0); Brilly and Polic, 2005; Zaalberg et al., 2009;</td>
</tr>
<tr>
<td><strong>Coping appraisals:</strong></td>
<td></td>
<td></td>
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<tr>
<td>Perceived self-efficacy</td>
<td>+/-0</td>
<td>Floyd et al., 2000; Grothmann and Reusswig, 2006; Loke et al., 2012; Martel and Mueller, 2011; Milne et al., 2000; Mishra and Suar, 2012; Peak et al., 2010; Weiss et al., 2011; McIvor and Paton, 2007; Poussin et al., 2013; Sjöberg, 1999; Zaalberg et al., 2009; Harries, 2012; Paton et al., 2006;</td>
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<tr>
<td>Locus of control</td>
<td>+/-0</td>
<td>Baumann and Sims, 1978; Lin et al., 2008; Mileti and Peek, 2000; Norris et al., 1999; Paton et al., 2006; Sattler et al., 2000; McIvor and Paton, 2007; Ozdemir and Yilmaz, 2011; Karanci et al., 2005; Laska, 1990;</td>
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<tr>
<td>Lack of control</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Perceived response-efficacy = effectiveness of protection</td>
<td>+/-0</td>
<td>Defra, 2008; Floyd et al., 2000; Grothmann and Reusswig, 2006; Kreibich et al., 2005; Laska, 1990; Lindell and Perry, 2000; Milne et al., 2000; Neuwirth et al., 2000; Paton et al., 2006; Thieken et al., 2007; Zaalberg et al., 2009; Poussin et al., 2013; Harries, 2012; Terpstra, 2011;</td>
</tr>
<tr>
<td>Lack of effectiveness</td>
<td>-</td>
<td>Pynn and Ljung, 1999; Siegrist and Gutscher, 2008; Tekeli-Yesil et al., 2010b; Zaleskiewicz et al., 2002;</td>
</tr>
<tr>
<td>Benefit more to others (insurance)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Perceived efficiency of measures</td>
<td>+</td>
<td>Zaleskiewicz et al., 2003; Siegrist and Gutscher, 2008;</td>
</tr>
<tr>
<td>Lack of efficiency</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Perceived usefulness of measures</td>
<td>+/-0</td>
<td>Lindell and Perry, 2000;</td>
</tr>
<tr>
<td>Measures are unnecessary (indirect measure of risk perception)</td>
<td>-</td>
<td>Lindell and Perry, 2000;</td>
</tr>
<tr>
<td>Perceived response-cost of measures:</td>
<td>-</td>
<td>Grothmann and Reusswig, 2006; Siegrist and Gutscher, 2008;</td>
</tr>
<tr>
<td>Time</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Difficulty / complexity</td>
<td>Brilly and Polic, 2005; Grothmann and Reusswig, 2006; Zaleskiewicz et al., 2002;</td>
<td></td>
</tr>
<tr>
<td>Perceived impact on appearance of the home</td>
<td>Defra, 2008; Kunreuther, 2006;</td>
<td></td>
</tr>
<tr>
<td>Perceived impact on value of home</td>
<td>Harries, 2008 (-); Kunreuther, 2006 (-); Defra, 2008 (+/-);</td>
<td></td>
</tr>
<tr>
<td>Experience (Flood) experience</td>
<td>Baumann and Sims, 1978 (+); Diekman et al., 2007 (+); Harries, 2012 (+); Knocke and Kolivras, 2007 (+); Kreibich and Thieken, 2009 (+); Kreibich et al., 2005, 2009, 2011 (+); Lindell and Hwang, 2008 (+); Peak et al., 2010 (+); Sattler et al., 2000 (+); Siegrist and Gutsch, 2006, 2008 (+); Tekeli-Yesil et al., 2010b (+); Thieken et al., 2006, 2007 (+); Weiss et al., 2011 (+); Wind et al., 1999 (+); Zaleskiewicz et al., 2002 (+); Harries, 2008 (+/-); Harvatt et al., 2011 (+/0); Lindell and Perry, 2000 (+/0); Poussin et al., 2013 (+/0); Pynn and Ljung, 1999 (+/0); Chen et al., 2012 (0); Michel-Kerjan et al., 2012 (0); Sims and Baumann, 1987 (0); Takao et al., 2004 (0);</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>Laska, 1990 (+); Lindell and Perry, 2000 (+); Kunreuther et al., 1985 (+); Kreibich, 2011 (0);</td>
<td></td>
</tr>
<tr>
<td>Financial damage</td>
<td>Laska, 1990 (+); Kreibich, 2011 (+); Sims and Baumann, 1987 (+); Takao et al., 2004 (+); Thieken et al., 2007 (+); Lindell and Perry, 2000 (+/0); Kreibich et al., 2005 (-); Miceli et al., 2008 (0); Siegel et al., 2003 (0);</td>
<td></td>
</tr>
<tr>
<td>Perceived severity of event</td>
<td>Laska, 1990; Lindell and Perry, 2000; Grothmann and Reusswig, 2006;</td>
<td></td>
</tr>
<tr>
<td>Physical damage / death of household member</td>
<td>Lindell and Perry, 2000; Siegel et al., 2003;</td>
<td></td>
</tr>
<tr>
<td>Psychological damage</td>
<td>Sattler et al., 2000 (+); Siegel et al., 2003 (+/0);</td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td>Grothmann and Reusswig, 2006 (+); Norris et al., 1999 (+/0);</td>
<td></td>
</tr>
<tr>
<td>Evacuation</td>
<td>Thieken et al., 2007;</td>
<td></td>
</tr>
<tr>
<td>Compensation</td>
<td>Tekeli-Yesil et al., 2010b (+); Weiss et al., 2011 (+); Kreibich, 2011 (0);</td>
<td></td>
</tr>
<tr>
<td>Time since experience</td>
<td>Thieken et al., 2007;</td>
<td></td>
</tr>
<tr>
<td>Recency of experience</td>
<td>Sims and Baumann, 1987;</td>
<td></td>
</tr>
<tr>
<td>Feelings associated with previous experience</td>
<td>Terpstra, 2011;</td>
<td></td>
</tr>
<tr>
<td>Near-miss</td>
<td>Dillon et al., 2011;</td>
<td></td>
</tr>
<tr>
<td>Indirect experience</td>
<td>Grothmann and Reusswig, 2006 (+); Pynn and Ljung, 1999 (+); Lindell and Perry, 2000 (+/0);</td>
<td></td>
</tr>
<tr>
<td>Aspect</td>
<td>References</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Participated in rescue activities / cleaning up after event</td>
<td>Siegrist and Gutscher, 2006; Tekeli-Yesil et al., 2010a;</td>
<td></td>
</tr>
<tr>
<td>Flood history of area</td>
<td>Pynn and Ljung, 1999 (+); Weiss et al., 2011 (+/-);</td>
<td></td>
</tr>
<tr>
<td>Risk attitudes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-protective responses (denial, fatalism, wishful thinking, helplessness, anxiety avoidance)</td>
<td>Defra, 2008 (-); Grothmann and Reusswig, 2006 (-); Harries, 2008, 2012 (-); Harvatt et al., 2011 (-); Lin et al., 2008 (-); Weiss et al., 2011 (-); Lindell and Perry, 2000 (-/0);</td>
<td></td>
</tr>
<tr>
<td>Risk aversion:</td>
<td>Mclvor and Paton, 2007 (-); Pynn and Ljung, 1999 (-); Siegrist and Gutscher, 2008 (-); Tekeli-Yesil et al., 2010b (-); Weiss et al., 2011 (-); Lindell and Perry, 2000 (-/0);</td>
<td></td>
</tr>
<tr>
<td>Insurance purchasing</td>
<td>Mclvor and Paton, 2007 (towards specific hazard +); Tekeli-Yesil et al., 2010a (+); Ozdemir and Yilmaz, 2011 (+/0);</td>
<td></td>
</tr>
<tr>
<td>Do not buy insurances / risk taking</td>
<td>Thieken et al., 2006 (+); Defra, 2008 (already protected -);</td>
<td></td>
</tr>
<tr>
<td>Risk management policies and incentives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication / attention to media / warnings</td>
<td>Lindell and Perry, 2000 (+); Peak et al., 2010 (+); Sims and Baumann, 1987 (+); Thieken et al., 2007 (+); Zhai et al., 2006 (information on other risks -); Pynn and Ljung, 1999 (+/-); Milet and Peek, 2000 (+/0); Miceli et al, 2008 (0); Lindell and Perry, 2000; Milet and Peek, 2000;</td>
<td></td>
</tr>
<tr>
<td>Number of times (reinforcement)</td>
<td>Lindell and Perry, 2000 (+); Milet and Peek, 2000 (+); Weiss et al., 2011 (+); McLure et al, 2009 (framing +/-); Lin et al., 2008; Lindell and Perry, 2000; Milet and Peek, 2000; Paul and Routray, 2011; Weiss et al, 2011;</td>
<td></td>
</tr>
<tr>
<td>Quality/style and content</td>
<td>Weiss et al., 2011 (+/-); Sims and Baumann, 1987 (0);</td>
<td></td>
</tr>
<tr>
<td>Source and trust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type and intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government intervention before or after event, reliance on public protection, public compensation / Service interruption / No or insufficient help</td>
<td>Botzen et al., 2009b (-); Botzen and Van den Bergh, 2012b (-); Defra, 2008 (-); Paul and Routray, 2011 (-); Pynn and Ljung, 1999 (-); Grothmann and Reusswig, 2006 (/-0); Kunreuther, 2006 (0); Martel and Mueller, 2011 (from low to high); Pynn and Ljung, 1999;</td>
<td></td>
</tr>
<tr>
<td>– Regulation enforcing the undertaking of measures (new / existing buildings)</td>
<td>Brilly and Polic, 2005 (+); Spence, 2004 (+); Poussin et al., 2013 (0);</td>
<td></td>
</tr>
<tr>
<td>– Financial incentives provided by insurers (impact varies with types of incentives) or banks (mortgages)</td>
<td>Botzen et al., 2008; Botzen et al., 2009b; Defra, 2008; Kunreuther, 1996; Kunreuther and Pauly, 2006; Kunreuther, 2008; Pynn and Ljung, 1999; Spence, 2004;</td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>Symbol</td>
<td>References</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>Subsidies</td>
<td>+/-0</td>
<td>Poussin et al., 2013;</td>
</tr>
<tr>
<td>Awareness and preparedness training</td>
<td></td>
<td>Karanci et al., 2005; Miceli et al., 2008;</td>
</tr>
<tr>
<td>Trust in government capacity with regard to crisis management</td>
<td></td>
<td>Lin et al., 2008;</td>
</tr>
<tr>
<td>Lack of trust</td>
<td></td>
<td>Tekeli-Yesil et al., 2010b;</td>
</tr>
<tr>
<td>Perceived importance of climate change and flood protection policies</td>
<td></td>
<td>Kreibich, 2011;</td>
</tr>
<tr>
<td>Social network and social norms</td>
<td>+/-</td>
<td>Loke et al., 2012 (+); Mileti and Peek, 2000 (+); Zaleskiewicz et al., 2002 (insurance agent +); Pynn and Ljung, 1999 (real estate agent +, insurance agent +/-);</td>
</tr>
<tr>
<td>- Measures taken by others, neighbours</td>
<td>+</td>
<td>Kunreuther, 2006 (+); Lindell and Perry, 2000 (+); Tekeli-Yesil et al., 2010b (+); Zaleskiewicz et al., 2002 (+); Pynn and Ljung, 1999 (+/-);</td>
</tr>
<tr>
<td>- Help received from social network</td>
<td>+</td>
<td>Paul and Routray, 2011;</td>
</tr>
<tr>
<td>- Subjective norm ('network think that')</td>
<td>+/-0</td>
<td>Peak et al., 2010 (+); McIvor and Paton, 2007 (positive +, negative 0);</td>
</tr>
<tr>
<td>- Perceived norm ('population in general')</td>
<td>+/-0</td>
<td>Harries, 2008 (-); Lindell and Perry, 2000 (+/-); Peak et al., 2010 (+/0);</td>
</tr>
<tr>
<td>- Stigma</td>
<td>0</td>
<td>Harries, 2012;</td>
</tr>
<tr>
<td>- Relation to neighbours / neighbourhood belonging</td>
<td>+/-0</td>
<td>Lindell and Perry, 2000 (+); Paton et al., 2006 (+); Kim and Kang, 2010 (+/0);</td>
</tr>
<tr>
<td>Socio-economic characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demographic characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>+/-0</td>
<td>Kreibich, 2011 (+); Miceli et al., 2008 (+); Mishra and Suar, 2012 (+); Norris et al., 1999 (+); Sattler et al., 2000 (+); Sims and Baumann, 1987 (+); Tekeli-Yesil et al., 2010a (+); Weiss et al., 2011 (+); Brilly and Polic, 2005 (-); Pynn and Ljung, 1999 (-); Soane et al. (2010) (-); Knoke and Kolivras, 2007 (+/-); Lindell and Perry, 2000 (+/0); Paul and Routray, 2011 (+/0); Peak et al., 2010 (+/0); Ozdemir and Yilmaz, 2011 (-/0); Botzen et al., 2009b (o); Floyd et al., 2000 (o); Grothmann and Reusswig, 2006 (o); Karanci et al., 2005 (o); Kim and Kang, 2010 (o);</td>
</tr>
<tr>
<td><strong>Gender (female)</strong></td>
<td>Lindell and Perry, 2000 (+); Karanci et al., 2005 (-); Paul and Routray, 2011 (-); Tekeli-Yesil et al., 2010a (-); Knocke and Kolivras, 2007 (+/-); Weiss et al., 2011 (+/-, take different measures); Kim and Kang, 2010 (+/0); Peak et al., 2010 (+/0); Norris et al., 1999 (-/0); Ozdemir and Yilmaz, 2011 (-/0); Botzen et al., 2009b (0); Miceli et al., 2008 (0); Sims and Baumann, 1987 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Marital status</strong></td>
<td>Tekeli-Yesil et al., 2010a;</td>
<td></td>
</tr>
<tr>
<td><strong>Married</strong></td>
<td>Lindell and Perry, 2000 (+); Karanci et al., 2005 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Divorced</strong></td>
<td>Ozdemir and Yilmaz, 2011;</td>
<td></td>
</tr>
<tr>
<td><strong>Income (impact depends on measures considered)</strong></td>
<td>Baumann and Sims, 1978 (+); Laska, 1990 (+); Lin et al., 2008 (+); Lindell and Hwang, 2008 (+); Mishra and Suar, 2012 (+); Paul and Routray, 2011 (+); Sattler et al., 2000 (+); Soane et al., 2010 (+); Zhai et al., 2006 (+); Kunreuther, 2006 (+/-); Grothmann and Reusswig, 2006 (+/0); Lindell and Perry, 2000 (+/0); Ozdemir and Yilmaz, 2011 (+/0); Botzen et al., 2009b (0); Kim and Kang, 2010 (0); Kreibich et al., 2005 (0); Sims and Baumann, 1987 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Ownership</strong></td>
<td>Harvatt et al., 2011 (+); Kreibich et al., 2005 (+); Kreibich, 2011 (+); Lindell and Perry, 2000 (+); Mishra and Suar, 2012 (+); Takao et al., 2004 (+); Tekeli-Yesil et al., 2010a (+); Thieken et al., 2007 (+); Karanci et al., 2005 (-); Grothmann and Reusswig, 2006 (+/0); Paul and Routray, 2011 (+/0); Peak et al., 2010 (+/0); Kim and Kang, 2010 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>Baumann and Sims, 1978 (+); Botzen et al., 2009b (+); Karanci et al., 2005 (+); Lin et al., 2008 (+); Mishra and Suar, 2012 (+); Paul and Routray, 2011 (+); Soane et al., 2010 (+); Tekeli-Yesil et al., 2010a, b (+); Wamsler et al., 2012 (+); Lindell and Perry, 2000 (+/-/0); Norris et al., 1999 (+/-/0); Kim and Kang, 2010 (0); Miceli et al., 2008 (0); Sims and Baumann, 1987 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Size of household</strong></td>
<td>Kreibich et al., 2005 (+); Mishra and Suar, 2012 (+); Karanci et al., 2005 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>(Number of) children/dependent people</strong></td>
<td>Barata et al., 2004 (+); Diekmann et al., 2007 (+); Kreibich, 2011 (+); Loke et al., 2012 (+); Pynn and Ljung, 1999 (+); Baker and Baker, 2010 (+); Bethel et al., 2011 (+/-); Uscher-Pines et al., 2009 (+/-); Lindell and Perry, 2000 (+/0); Peak et al., 2010 (0); Tekeli-Yesil et al., 2010a (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Profession</strong></td>
<td>Paul and Routray, 2011 (+/-); Sims and Baumann, 1987 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Social class</strong></td>
<td>Sims and Baumann, 1987;</td>
<td></td>
</tr>
<tr>
<td><strong>Social ties, recognition in the community, social rank</strong></td>
<td>Mishra and Suar, 2012 (+); Kreibich, 2011 (-); Peak et al., 2010 (0);</td>
<td></td>
</tr>
<tr>
<td><strong>Self-expressed economic status</strong></td>
<td>Tekeli-Yesil et al., 2010a;</td>
<td></td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td>Lindell and Perry, 2000 (white +); Lindell and Hwang, 2008 (white +); Weiss et al., 2011 (+/-); Norris et al., 1999 (+/0); Kim and Kang, 2010 (white 0); Peak et al., 2010 (white 0);</td>
<td></td>
</tr>
<tr>
<td><strong>Birthplace (China)</strong></td>
<td>Loke et al., 2012;</td>
<td></td>
</tr>
<tr>
<td><strong>(Im)migrant status</strong></td>
<td>Lindell and Perry, 2000 (+); Paul and Routray, 2011 (-);</td>
<td></td>
</tr>
<tr>
<td><strong>Home characteristics</strong></td>
<td>Karanci et al., 2005;</td>
<td></td>
</tr>
<tr>
<td><strong>Value of home, value of content</strong></td>
<td>+/-/0</td>
<td>Ozdemir and Yilmaz, 2011 (-); Pynn and Ljung, 1999 (+/-); Lindell and Perry, 2000 (+/0);</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Household properties (number of items in house)</strong></td>
<td>0</td>
<td>Karanci et al., 2005;</td>
</tr>
<tr>
<td><strong>Age of home</strong></td>
<td>+/-0</td>
<td>Lindell and Perry, 2000 (+/0); Kreibich et al., 2005 (0);</td>
</tr>
<tr>
<td><strong>Time living in home / area</strong></td>
<td>+/-0</td>
<td>Pynn and Ljung, 1999 (-); Weiss et al., 2011 (+/-); Lindell and Perry, 2000 (+/0); Kim and Kang, 2010 (0); Sims and Baumann, 1987 (0);</td>
</tr>
<tr>
<td><strong>Expect to stay in home for short time</strong></td>
<td>-/0</td>
<td>Defra, 2008 (-); Harries, 2012 (-); Lindell and Hwang, 2008 (0);</td>
</tr>
<tr>
<td><strong>Increased time estimated/willing to stay in home</strong></td>
<td>-</td>
<td>Laska, 1990 (for insurance purchasing -);</td>
</tr>
<tr>
<td><strong>Elevation of the house, but protection lower than water level</strong></td>
<td>-</td>
<td>Botzen et al., 2009b;</td>
</tr>
<tr>
<td><strong>Proximity to source of flooding (distance decreases)</strong></td>
<td>+/-0</td>
<td>Botzen et al., 2009b (+); Brilly and Polic, 2005 (+); Lindell and Hwang, 2008 (+); Miceli et al., 2008 (+); Pynn and Ljung, 1999 (+); Zhai et al., 2006 (+); Paul and Routray, 2011 (distance to sea for cyclones -); Lindell and Perry, 2000 (distance to fault lines +/0);</td>
</tr>
<tr>
<td><strong>Living in flood-prone / hazard-prone area</strong></td>
<td>+/-0</td>
<td>Ozdemir and Yilmaz, 2011 (+); Pynn and Ljung, 1999 (+); Tekeli-Yesil et al., 2010a, b (+); Norris et al., 1999 (+/0); Michel-Kerjan, et al., 2012 (0);</td>
</tr>
<tr>
<td><strong>Living behind a levee</strong></td>
<td>-</td>
<td>Burby, 2006;</td>
</tr>
<tr>
<td><strong>Location (rural area)</strong></td>
<td>+/-0</td>
<td>Botzen et al., 2009b (+); Peak et al., 2010 (0);</td>
</tr>
<tr>
<td><strong>Location (different regions)</strong></td>
<td>+/-/-0</td>
<td>Poussin et al., 2013 (+/0); Lindell and Perry, 2000 (+/-0); Michel-Kerjan et al., 2012 (0);</td>
</tr>
<tr>
<td><strong>Socio-economic level (SEL) of area</strong></td>
<td>+/-0</td>
<td>Tekeli-Yesil et al., 2010a;</td>
</tr>
<tr>
<td><strong>Low SEL</strong></td>
<td>-/0</td>
<td>Tekeli-Yesil et al., 2010b;</td>
</tr>
<tr>
<td><strong>Personality traits</strong></td>
<td>+/-</td>
<td>Weiss et al., 2011;</td>
</tr>
<tr>
<td><strong>Perceived responsibility for preparedness</strong></td>
<td>+/-/-0</td>
<td>Botzen et al., 2009b (-); Lindell and Perry, 2000 (-); Ozdemir and Yilmaz, 2011 (+/0); Harries, 2012 (0);</td>
</tr>
<tr>
<td><strong>Government</strong></td>
<td>-</td>
<td>Harries, 2008; Soane et al, 2010;</td>
</tr>
<tr>
<td><strong>Regulators</strong></td>
<td>+</td>
<td>Soane et al, 2010;</td>
</tr>
<tr>
<td><strong>Scientists</strong></td>
<td>+/-/-0</td>
<td>Martel and Mueller, 2011 (+); Lindell and Perry, 2000 (+); Weiss et al., 2011 (+); Ozdemir and Yilmaz, 2011 (-/0); Laska, 1990 (0);</td>
</tr>
<tr>
<td><strong>Self</strong></td>
<td>-</td>
<td>Harvatt et al., 2011;</td>
</tr>
<tr>
<td><strong>Not self, others</strong></td>
<td></td>
<td>Harvatt et al., 2011;</td>
</tr>
<tr>
<td><strong>Short time horizon</strong></td>
<td>-</td>
<td>Kunreuther, 2006;</td>
</tr>
<tr>
<td><strong>Place attachment</strong></td>
<td>+/-/-0</td>
<td>Zaleskiewicz et al, 2002 (+); Weiss et al., 2011 (+/-); Mishra et al, 2010 (genealogical +, economical +, religious 0);</td>
</tr>
<tr>
<td>Factor</td>
<td>Effect</td>
<td>References</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------</td>
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</tr>
<tr>
<td>Information seeking</td>
<td>+</td>
<td>Lindell and Perry, 2000; Thieken et al., 2007;</td>
</tr>
<tr>
<td>Engagement personality</td>
<td>+/-</td>
<td>Brilly and Polic, 2005 (+); Weiss et al., 2011 (+); Sims and Baumann, 1987 (o);</td>
</tr>
<tr>
<td>Cognitive abilities</td>
<td>+/-</td>
<td>Schoemaker and Kunreuther, 1979 (+); Weiss et al., 2011 (+); Mileti and Peek, 2000 (+/o);</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-</td>
<td>Mishra and Suar, 2012;</td>
</tr>
</tbody>
</table>

Note: All the studies in the table are original publications, except: the review articles by Floyd et al. (2000) and Milne et al. (2000), who reviewed studies conducted on PMT for health-related behaviour; Lindell and Perry (2000), who reviewed studies on mitigation behaviour relating to earthquakes by households; Mileti and Peek (2000), who reviewed studies on the process of public responses to warnings; and Weiss et al. (2011), who reviewed French studies on factors influencing mitigation behaviour. The studies reviewed in these five articles are not included individually in Table B-1.

a Zaalberg et al. (2009) study the impact of the response-efficacy of prevention and the response-efficacy of adaptation on prevention (stop waters) and adaptation (adapt to waters) to future damage. They find positive effects of response-efficacy of prevention and adaptation on prevention and adaptation behaviour. An exception is that the response-efficacy of adaptation has a negative significant effect on prevention; i.e. people who believe that adaptation is effective in decreasing damage do not take (more) preventive action.

b Study in Hong Kong.
B2 Description of variables elicited by the survey

Table B-2 describes the mitigation measures that have been used for constructing the dependent variables of the regression models. The measures are classified by the authors into three groups: namely, structural measures; avoidance measures; and emergency preparedness measures (Bubeck et al., 2012b; Grothmann and Reusswig, 2006; Kreibich et al., 2005). In France, the natural disaster coverage is, in most cases, compulsory for homeowners and tenants. Therefore, almost all households have property insurance and natural disaster coverage (Michel-Kerjan, 2010). Hence, the purchase of natural disaster insurance was not asked for in the survey.

Structural measures include changes made to the structure of a house or a building with the objective to reduce flood risk (Bubeck et al., 2012b; Grothmann and Reusswig, 2006). They are generally high-cost measures that are implemented in advance of a flood threat. Avoidance measures are measures that are meant to avoid damage by adapting the interior of a home (Bubeck et al., 2012b; ICPR, 2002; Kreibich et al., 2005). These measures are generally low-cost measures that are implemented in advance of the flood threat. Emergency preparedness measures include all the measures which are meant to prepare the household to react to imminent flood threats by, for instance, buying and keeping flood protection devices (Grothmann and Reusswig, 2006). These measures should be distinguished from emergency measures stricto sensu (s.s.), which are measures that are to be taken just before or during a flood to limit the entrance of floodwaters into the home, and to mitigate flood damage (Bubeck et al., 2012b; ICPR, 2002). They were not included in the survey because their implementation is highly dependent on factors which are exogenous to the respondents, such as the time between the warning and the beginning of the flood, or the presence or absence of household members in the home when a flood starts. Emergency preparedness measures are meant to facilitate the undertaking of emergency measures s.s. They are generally low-cost measures. They can be undertaken at any time before a flood.
### Table B-2 Mitigation measures included in the questionnaire.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Measures</th>
</tr>
</thead>
</table>
| Structural measures   | The level of the ground floor is raised above the most likely flood level  
                         | The foundations are strengthened against water pressures  
                         | The walls and equipment of the ground floor are made with water-resistant materials  
                         | The floor of the ground floor is made of water-resistant materials  
                         | The electricity meter is above the most likely flood level or on an upper floor  
                         | In the house/apartment, the power sockets are above the most likely flood level  
                         | Anti-backflow valves are installed on pipes  
                         | The house/apartment has a refuge zone, or an opening in the roof  
                         | If the respondent has a cellar: the walls and equipment of the cellar are made of water-resistant materials  
                         | If the respondent has a cellar: the floor of the cellar is made of water-resistant materials  
                         | If the respondent has a cellar: in the cellar, the power sockets are above the most likely flood level  
                         | A pump is installed  
                         | If the respondent lives in a house: one or more system(s) to drain waters are installed  
                         | A protective barrier is built around the house or the grounds to stop the waters (a wall for instance)*                                                                                              |
| Avoidance measures    | The boiler / heater are above the most likely flood level or on an upper floor  
                         | The washing machine / dryer are above the most likely flood level or on an upper floor  
                         | In flood-prone parts of home, the furniture is chosen and placed to avoid flood damage  
                         | Personal and important documents are stored above the most likely flood level or on an upper floor  
                         | If the respondent has or had an oil tank: the oil tank has been anchored or removed  
| Emergency preparedness measures | Own sandbags, or other water barriers  
                         | A “family emergency plan” has been made with other members of the household  
                         | If the respondent has a pump: the pump is maintained or checked regularly  
                         | A power generator is kept in the home*  
                         | Breeze blocks or equipment to raise the furniture before or during a flood are kept in storage*                                                                                                        |

Source: Survey conducted in 2011 in France by the authors.

Note: * Measures added by the respondents in an open-ended question.
Table B-3 defines the variables included in the regression models. Next, the explanatory variables will be described below.

Table B-3 Overview of the variables used in the statistical analysis, and their coding.

<table>
<thead>
<tr>
<th>Dependent variables:</th>
<th>Explained by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural measures</td>
<td>Continuous variable of the number of structural measures implemented in the home</td>
</tr>
<tr>
<td>Avoidance measures</td>
<td>Continuous variable of the number of avoidance measures implemented in the home</td>
</tr>
<tr>
<td>Emergency preparedness measures</td>
<td>Continuous variable of the number of emergency preparedness measures implemented in the home</td>
</tr>
<tr>
<td>Intentions</td>
<td>Categorical variable, respondent’s intentions to implement (additional) measures in the near future: 1 = certainly not, 2 = probably not, 3 = probably, 4 = certainly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Explanatory variables:</th>
<th>Explained by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threat appraisals</td>
<td></td>
</tr>
<tr>
<td>Perception of flood damage</td>
<td>Categorical variable, respondent expects future damage to be: 1 = very small, 2 = small, 3 = medium, 4 = high, 5 = very high</td>
</tr>
<tr>
<td>Perception of flood probability</td>
<td>Categorical variable, respondent estimates the probability to be flooded as: 1 = never, 2 = low, 3 = medium, 4 = high, 5 = for sure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coping appraisals</th>
<th>Explained by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived self-efficacy</td>
<td>Categorical variable, respondent thinks that him/herself or a member of the household is capable of taking the described measures: 1 = not able at all, 2 = not able, 3 = not able, not unable, 4 = able, 5 = totally able</td>
</tr>
<tr>
<td>Perceived response-efficacy</td>
<td>Categorical variable, respondent perceives the measures to be: 1 = not effective at all, 2 = not effective, 3 = not effective, not ineffective, 4 = effective, 5 = very effective</td>
</tr>
<tr>
<td>Perceived response-cost</td>
<td>Categorical variable, respondent perceives the measures to take: 1 = a very short time to implement, 2 = a short time, 3 = a not short, not long time, 4 = a long time, 5 = a very long time</td>
</tr>
<tr>
<td>Time needed to implement the measures</td>
<td>Explained by:</td>
</tr>
<tr>
<td>Cost of the measures</td>
<td>Explained by:</td>
</tr>
<tr>
<td>Flood experience</td>
<td>Dummy variable, 1 = respondent has personally been flooded in home, cellar, or garage, 0 = otherwise</td>
</tr>
<tr>
<td>Flood damage</td>
<td>Continuous variable of the total damage to home and contents experienced during the last flood of the respondent</td>
</tr>
<tr>
<td>Number of times personally flooded</td>
<td>Continuous variable of the number of times the respondent has personally been flooded</td>
</tr>
<tr>
<td>Risk attitudes: Risk aversion</td>
<td>Categorical variable, respondent considers that people avoiding financial risk by purchasing insurance are: 1 = very different, 2 = different, 3 = not different, not similar, 4 = similar, 5 = very similar to themselves</td>
</tr>
<tr>
<td>Flood risk management policies and incentives</td>
<td>Explained by:</td>
</tr>
<tr>
<td>Communication on risk</td>
<td>Dummy variable, 1 = respondent has received or looked for information on his risk</td>
</tr>
<tr>
<td>Looked for information on flood protection</td>
<td>Dummy variable, 1 = respondent has looked for information on flood protection measures</td>
</tr>
<tr>
<td>Received information on flood protection</td>
<td>Dummy variable, 1 = respondent has received information on flood protection measures</td>
</tr>
</tbody>
</table>
Feeling of being protected by public measures: Categorical variable, respondent feels protected against future floods: 1 = very badly-protected, 2 = badly-protected, 3 = not well-, not badly-protected, 4 = well-protected, 5 = very well-protected

Incentive from municipality (including PPRs): Dummy variable, 1 = respondent has taken measures because he/she was obliged or received a strong incentive to do so by the municipality (includes PPRs)

Incentive from insurers: Dummy variable, 1 = respondent has taken measures because he/she was obliged to do so, or received a strong incentive to do so by insurer

Incentive from others: Dummy variable, 1 = respondent has taken measures because he/she was obliged to do so, or received a strong incentive to do so from other sources than municipality or insurer

Social network and social norms: Mitigation measures taken by friends, family, or neighbours: Dummy variable, 1 = yes, 0 = otherwise ("no" and "do not know")

Socio-economic characteristics:

Age: Continuous variable, respondent enters year of birth; modified as age in 2011

Women: Dummy variable, 1 = female, 0 = male

Income: Continuous variable of net monthly income

Ownership of the home: Dummy variable, 1 = owner of home, 0 = tenant

Education level: Categorical variable, years of study after 11 years old, 1 = zero (no diploma), 2 = one (CEP), 3 = three (BEPC), 4 = seven (CAP, BEP, Baccalauréat), 5 = nine (Bac+2), 6 = eleven (Bac+3, +4), 7 = twelve (Bac+5 and above)

Size of the household: Categorical variable, 0 = zero, 1 = one, 2 = two, 3 = more than 2 people in household

Location:

Ardennes: Dummy variable, 1 = Ardennes, 0 = not Ardennes

West: Dummy variable, 1 = West, 0 = not West

Notes: * The regression model includes interactions of this variable with the location variables; b In the questionnaire, 9 answer categories of income were provided (e.g. between 1,000 and 1,250 euros) on the basis of which a continuous income variable was created by taking the midpoint of the answered intervals.

**Threat appraisals** for floods are assessed by variables of the respondents’ perceived flood damage and perceived flood probability. A variable of respondents’ fear or worry about future flooding was not included in the regressions because it is highly correlated with perceived flood damage.

**Coping appraisals** are assessed by using questions that elicit the respondents’ perceived self-efficacy, the perceived response-efficacy, and response-cost of the flood mitigation measures. The coping appraisal questions in the survey were included twice to assess coping appraisal separately for structural measures, and for avoidance and emergency preparedness measures. For avoidance and emergency preparedness measures, these questions were combined because both these types of measures can be considered relatively easy and non-expensive compared with structural measures.
Flood experience can be defined as ‘having experienced a flood in the past’ and can be described by various characteristics, such as the financial damage suffered or the time since the experience (Table B-1). These characteristics of the flood may be a reason for the implementation of measures by households. However, water height and financial damage may decrease after mitigation measures have been implemented. In cross-sectional surveys, this may result in a weak or negative relationship between flood experience and mitigation behaviour because the measurements of the flood experience (e.g. water height, financial damage) are conducted after the installation of measures have occurred. Therefore, in this study, only the variable ‘flood experience’ in general (i.e. having been personally flooded in the home, the cellar, the crawl space, or the garage) is used to explain protective behaviour. Two separate interaction variables, the total flood damage experienced during the respondents’ last flood and the number of times the respondents have personally been flooded, were also used in additional regressions in order to explain the results obtained in the final models described in Section 3.3.

Risk attitudes’ effects on disaster preparedness have been examined by the economics literature which commonly postulates that a single personality trait (i.e. risk-averse, risk-neutral, or risk-loving) determines behaviour under risk in all contexts. Expected Utility Theory (EUT) (Von Neumann and Morgenstern, 1947) assumes that individuals rationally assess the likelihood and consequences of a hazard, and that individuals who are characterized as risk-averse will protect themselves against a risk if it is cost-effective to do so. Such a risk attitude is not included in traditional PMT. In the survey, risk attitudes are assessed using a question that elicits the individual’s risk aversion with respect to insurance purchases. Eliciting a single risk aversion variable was motivated by the work of Dohmen et al. (2011), who empirically show that a single risk-aversion trait governs individual behaviour toward a broad variety of risks in different contexts. The risk-aversion variable is derived from the answers to a question in which respondents indicated how similar to themselves they regard a person who avoids taking financial risks and prefers to be well-insured20. It has been shown by other studies that a risk-aversion variable derived from such a question is positively related to demand for flood preparedness in the Netherlands (Botzen and Van den Bergh, 2012a,b).

20. The question corresponds to a common format in psychological studies (e.g. Schwartz et al., 2001): “Some people avoid financial risks as much as possible. They are also well insured. How similar are these people to you?” with answer options “extremely similar to me”, “very similar to me”, “similar to me”, “a little bit like me”, “not similar to me”, and “not similar to me at all”.

Flood damage mitigation investments
Flood risk management policies and incentives can influence the implementation of flood damage mitigation measures by households in flood-prone areas. In the survey, the influence of French policies and incentives on respondents’ behaviour is accounted for by using several variables. One question controls for the effect of information received or looked for by the respondents on their risk and available protection measures. The survey did not ask for more details about the type of information. Another question was included on the feeling experienced by respondents of being protected against floods by public defences. This feeling of security can undermine their willingness to undertake mitigation measures. In France, natural disaster coverage premiums are fixed by the government independently of the policyholders’ risk and mitigation behaviour\(^{21}\) (Poussin et al., 2013). This means that French insurers cannot encourage the adoption of mitigation measures by providing premium discounts. However, they can influence households’ flood preparedness by providing them with adequate information on risk and measures. In addition, flood maps and complementary guidance reports, the Risk Prevention Plans (PPRs), are created by the government for the flood-prone areas and propose measures to reduce flood risk. To assess the influence of insurers and the municipality, comprising the influence of PPRs, two questions were included in the survey which ask whether or not respondents took measures in response to incentives provided by their insurer or their municipality. In contrast, the respondents could also reply that they had implemented their measures following incentives received from “other” sources. Aside from PPRs, the government also provides subsidies for the undertaking of protection measures. To assess the influence of these subsidies, a question was included in the survey which asked respondents who had taken mitigation measures how they had paid for these measures\(^{22}\). However, the results show that subsidies are almost never used by households to pay for their measure(s)\(^{23}\), which is why this variable is not included in the regression analyses.

Social networks and social norms have been shown to have a potentially large influence on the willingness of households to implement protection measures (Harries, 2008, 2012; Kunreuther et al., 1978). Although social networks can have mixed effects on flood preparedness, depending on whether mitigation measures are viewed positively by others, we hypothesize a positive influence on mitigation behaviour, which

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\(^{21}\) The natural disaster premium is 12% of, and added to, the property premium (Poussin et al., 2013).

\(^{22}\) The answer options are “previous compensation from insurance”, “subsidy”, “own funds”, “did not pay the measures themselves”, and “other”.

\(^{23}\) Only two respondents out of the 832 who took flood mitigation measures used subsidies to pay for their measure(s).
is in line with the findings of our literature review. The social network’s influence on the respondents’ mitigation behaviour was elicited with a question that asked whether or not some of the respondents’ close friends, family, or neighbours had taken measures to protect their home against floods. Using the answers to this question, we can assess both the positive and negative influences of the social network on mitigation behaviour.

Socio-economic characteristics can also have an influence on the implementation of mitigation measures. However, the evidence on the influence of socio-economic factors on flood preparedness is mixed, and varies between contexts and studies (Bubbeck et al., 2012b; Kellens et al., 2012). These characteristics were measured by including several questions in the survey. These variables include “demographic characteristics”, such as age, gender, or income. Regional effects on flood preparedness are accounted for in each regression model by including two dummy variables which control for the variation of mitigation behaviour that arises from the regional location of the home in the Ardennes or the West, compared with the Var. In addition, the regression models allow the effects on flood preparedness of threat appraisals, coping appraisals, and flood experience to differ between the three regions, by including in the regression models the interactions of these variables and the dummy variables of the Ardennes and the West. Only significant interactions of the regional dummies and these other variables are included in the final regression models that are reported in Section 3.3.
Appendix C

Questionnaire: Version sent to Ardennes and the Var

Instructions

This questionnaire is divided in five parts of different length. At the beginning of some parts, a small introduction presents the subject and gives recommendations or clarifications for answering it. Some questions can be quite general because this questionnaire is distributed in 4 departments. These questions are still very important for this research. Please find below some suggestions for filling out the survey:

- Most questions can be answered by ticking, encircling, or crossing your answer among the answer categories provided to you;
- Some questions are presented as a table; in that case you can easily indicate your answer with a cross in the table;
- Sometimes a note in parenthesis and italics indicates that multiple answers are possible;
- The survey includes a few open-ended questions without answer categories, for which you will be asked to fill out the blanks;
- For some questions it is indicated that they are specifically meant for certain people (such as people who own a car, who have personally experienced a flood, who live in a house, etc.). Please leave the answers blank if the characteristics described in the question do not correspond to you.
- Finally, sometimes a remark is placed in a box with information on a question and how it should be answered;

Each part and question of this questionnaire has its relevance. We would be most grateful to you if you could fill-in each of them with care and sincerity. There are no right or wrong answers.

Best regards,

Jennifer Poussin
A – CURRENT QUALITY of LIFE

Q1. First, on a scale from 0 to 10, where 0 means totally unhappy and 10 means totally happy, how satisfied are you with your life as a whole?

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Q2. Similarly, on a scale from 0 to 10, where 0 means totally unhappy and 10 means totally happy, how satisfied are you with the following domains of your life?

If you are retired or unemployed, you can leave the row “your job” blank.

<table>
<thead>
<tr>
<th>Domains</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your health</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your home</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your environment of living</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your job</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your personal income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your financial situation in general</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your amount of free time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The use of your free time</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your family life</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your social life</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q3. In the last six months, how often have you experienced the following feelings, “never”, “rarely”, “sometimes”, “often” or “very often”.

<table>
<thead>
<tr>
<th>Feelings</th>
<th>Very often</th>
<th>Often</th>
<th>Sometimes</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anxious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Happy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B - RISK PERCEPTION

Q4. How high do you estimate the probability that your property will be damaged in the future by the following events?
If you do not own a car, leave the row "car theft" blank.

<table>
<thead>
<tr>
<th>Events</th>
<th>Never</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car theft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burglary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire in your home</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrorist attack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear accident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic accident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flood/(from a source such as rain, underground or river water)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q5. Some people try to avoid financial risk as much as possible. They are also well insured. How similar are these people to you?

- □ Very similar to me
- □ Similar to me
- □ Not similar and not different to me
- □ Not similar to me

Q6. How do you rate your flood risk compared with an average person in France?

- □ I have a higher than average flood risk
- □ I have an average flood risk
- □ I have a lower than average flood risk

Q7. How much do you generally worry about the possibility of future flooding of your property?

- □ Very much
- □ A lot
- □ Average
- □ Little
- □ Not at all

Q8. How low or high do you expect that the potential damage of a future flood can be to your property and your belongings?

- □ Very high
- □ High
- □ Average
- □ Low
- □ Very low

Q9. In general, how often do you follow the weather forecasts?

- □ Very often
- □ Often
- □ Sometimes
- □ Rarely
- □ Never

Q10. Do you expect that your personal flood risk in the future will...

- □ Increase strongly
- □ Increase slightly
Q11. Who do you feel is responsible for flood prevention? Flood prevention here is the fact of organizing and preparing for possible floods. You can give multiple answers. If you do so, please rank your answers from the most responsible to the least responsible.

- [ ] Stay the same
- [ ] Decrease slightly
- [ ] Decrease strongly

Q12. To what extent do you agree or disagree with the following sentence: “There is nothing that can be done to stop floods from happening or to decrease flood damage”?

- [ ] Strongly agree
- [ ] Agree
- [ ] You do not have a clear opinion
- [ ] Disagree
- [ ] Strongly disagree

Q13. Have you ever received or personally looked for information on your flood risk (multiple answers are possible)?

- [ ] I received information
- [ ] I personally looked for information
- [ ] Neither of these
C - FLOOD EXPERIENCE

The following questions ask more details about your experience of floods. Please answer these questions only for your main residence.

(Floods are defined as events "when water from underground, river or rainwater enters homes, cellars, garages, crawl spaces or buildings").

Q14. Have you personally experienced or been witness of one or more floods, and if so how often did it happen to you (multiple answers are possible)?

☐ I personally experienced a flood, /_/ /_ times

☐ I witnessed a flood /_/ /_ times

☐ No (go to Q15)

Q14.1. Have your closest neighbors been flooded while you were not, or has floodwater ever almost entered your home?

1) /_/ /_ /_ /_ /_

2) /_/ /_ /_ /_ /_

3) /_/ /_ /_ /_ /_

Q14.2. Have you ever been flooded in a previous home?

1) /_/ /_ /_ /_ /_

2) /_/ /_ /_ /_ /_

3) /_/ /_ /_ /_ /_

Q14.2.1. If yes, did you move from this home because of this (or these) flood(s)?

1) /_/ /_ /_ /_ /_

2) /_/ /_ /_ /_ /_

3) /_/ /_ /_ /_ /_

Q14.3. Have you ever been flooded in your present home?

1) /_/ /_ /_ /_ /_

2) /_/ /_ /_ /_ /_

3) /_/ /_ /_ /_ /_

Remark: The next questions concern the flood that you experienced personally during which water entered your home, cellar, crawl space or garage.

If you have experienced more than one, then this flood is the last flood that you experienced personally.

If you have not experienced a flood, go directly to Q14.3.6.

Q14.3.1. Please specify the address in which this flood happened:

Address: …………………………………………………………………..

Postal code: /_/ /_ /_ /_

Town: ……………………………………………………………………….

Q14.3.2. Were you present in your home when the flood happened?  ☐ Yes  ☐ No

Q14.3.3. Where was the water coming from?

☐ Underground (rising from the ground)

☐ River or rain (from the street)

☐ Rising from pipes caused by river or rainwater
Q14.3.4. How high was the water in the flooded part(s) of your home?
If you do not remember well the water heights, you can use the following categories.

<table>
<thead>
<tr>
<th>Parts flooded</th>
<th>(cm or m) Water height</th>
<th>Less than 20 cm</th>
<th>Between 20 and 50 cm</th>
<th>Between 50 cm and 1 m</th>
<th>Between 1 m and 2 m</th>
<th>More than 2 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First floor</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Other: ..........</td>
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</tbody>
</table>

Q14.3.5. Did you have material damage?  □ Yes  □ No (go to Q14.3.6)

Q14.3.5.1. How much was the total damage in Euros (see remark)?
□ The damage cannot be expressed in a monetary value
□ ........................................ Euros of damage to my home or (other) buildings
□ ........................................ Euros of damage to my home contents

**Remark:** If you do not remember well the amount, you can use the following categories:

a) Less than 1,000 Euros
b) Between 1,000 and 5,000 Euros
c) Between 5,000 and 10,000 Euros
d) Between 10,000 and 50,000 Euros
e) Between 50,000 and 100,000 Euros
f) More than 100,000 Euros, approximately.............

Q14.3.5.2. After the flood, were you compensated?
□ Yes
□ I am still waiting for a compensation (go to Q14.3.6)
□ No (go to Q14.3.6)

Q14.3.5.2.1. If yes, approximately how much of your total damage was compensated?
□ 1 to 25%  □ 26 to 50%  □ 51 to 75%  □ 76 to 100%
Q14.3.6. During or following the flood…

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Without lasting consequences</th>
<th>With lasting consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were you physically hurt?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One or more of your household members were physically hurt</td>
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<td></td>
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<td></td>
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<tr>
<td>Were you psychologically hurt?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One or more of your household members were psychologically hurt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q14.3.7. Did one or more of your household members die during or because of the flood?

- Yes
- No

Q14.3.8. Were you disturbed in your capacity to earn your living or go to your work?

- Very much
- A lot
- Average
- Little
- Not at all

Q14.3.9. Were you scared for your life?

- Very much
- A lot
- Average
- Little
- Not at all

Q14.3.10. Did you get any sort of help from other people or from emergency services? If yes, from whom did you receive this help?

- Yes, from: ……………………………………………………………………….
- No

Q14.3.11. Have you been able to help close friends, relatives or neighbors?

- Yes
- No

Q14.3.12. Did the flood affect the life of your town in one of the following ways (multiple answers are possible)?

- It disturbed the life of the community
- It resulted in more tight community ties
- It resulted in strained community ties
- It hardly affected the community

Q14.4. Before the flood, do you remember how protected the public flood defenses made you feel?

- Very well protected
- Well protected
- Not well and not badly protected
- Badly protected
- Very badly protected
- I did not worry / did not care about this
Q14.5. After the flood, how satisfied were you with the effectiveness of these public flood defenses?

□ Very satisfied    □ Satisfied    □ Not satisfied, not dissatisfied
□ Dissatisfied    □ Very dissatisfied

Q14.6. Before the flood, did you receive an official warning? □ Yes     □ No

Q14.6.1. If yes, how long before the flood started in your home or neighborhood, did you get this warning?
_/_/ Minutes / Hours / Days / Weeks (encircle your answer)

Remark: The next questions concern:
□ Emergency measures: they are taken just before or during the flood, such as installing sandbags or moving belongings or furniture to higher floors.
□ Protection measures: they are taken in advance of the flood and before the forecast, to protect your home and contents. It is not necessary to describe these measures in this question, they will be described in more detail for the questions in part D;

Q14.7. Did you take emergency measures just before or during the flood, or protection measures?
□ Yes
□ No (go to Q14.8)

Q14.7.1. If yes, can you specify which ones?
□ Emergency measures before or during the flood: .................................................................
.................................................................
.................................................................

□ Protection measures (will be described in part D)

Q14.7.2. If you took measures: after the flood, how satisfied were you with the effectiveness of these measures?
□ Very satisfied    □ Satisfied    □ Not satisfied, not dissatisfied
□ Dissatisfied    □ Very dissatisfied

Q14.8. Before or during the flood, were you evacuated from your home? □ Yes     □ No
D - MITIGATION MEASURES

The next questions are specifically about measures that can be taken to protect homes against floods. Please answer these questions only for your main residence.

Q15. Have you ever received or personally looked for information on how to protect your home against floods (multiple answers are possible)?
[ ] I received information
[ ] I personally looked for information
[ ] Neither of these

Q16. How protected do you currently feel against future floods? Please explain your answer.
[ ] Very well protected
[ ] Well protected
[ ] Not well and not badly protected
[ ] Badly protected
[ ] Very badly protected
Why do you feel well or badly protected: .................................................................
........................................................................................................................................
........................................................................................................................................

Q17. In particular, how protected do the public defenses against future floods make you feel?
[ ] Very well protected
[ ] Well protected
[ ] Not well and not badly protected
[ ] Badly protected
[ ] Very badly protected

Q18. Currently, do you live in a house or an apartment? If it is an apartment, please specify on which floor you live.
[ ] House
[ ] Apartment, on the __/__/ floor

Q18.1. If you live in a house:

Q18.1.1. How many floors has your house above the ground floor?__/__/ floors

Q18.1.2. Do you have a cellar? [ ] Yes [ ] No

Q18.1.3. Do you have a crawl space*? [ ] Yes [ ] No

* Space of a few cm of height, between the ground and the first floor of the building

Q18.2. If you live in an apartment:

Q18.2.1. Do you use a cellar or a garage in your building?
[ ] Yes
[ ] No
Q19. Are the measures that are listed below implemented in or around your current home? 

With “above the most likely flood level”, we mean here “above the most likely water level during a flood”.

<table>
<thead>
<tr>
<th>Structural measures</th>
<th>Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>1. The level of the ground floor or the house/building itself is raised above the</td>
<td></td>
</tr>
<tr>
<td>most likely flood level (elevation, poles, etc.)</td>
<td>No</td>
</tr>
<tr>
<td>2. The foundations of the house/building are strengthened against pressures due to</td>
<td></td>
</tr>
<tr>
<td>flood-water</td>
<td></td>
</tr>
<tr>
<td>3. The walls and equipment of the ground floor such as the doors, the isolation and</td>
<td></td>
</tr>
<tr>
<td>the woodwork are made with materials resistant to water</td>
<td></td>
</tr>
<tr>
<td>4. The floor of your ground floor is made of materials resistant to water, such as</td>
<td></td>
</tr>
<tr>
<td>tiles</td>
<td></td>
</tr>
<tr>
<td>5. The electrical meter is above the most likely flood level, or on an upper floor</td>
<td></td>
</tr>
<tr>
<td>6. In the house/apartment, the power sockets are above the most likely flood level</td>
<td></td>
</tr>
<tr>
<td>7. Anti-backflow valves are installed on pipes, to prevent water from entering your</td>
<td></td>
</tr>
<tr>
<td>home</td>
<td></td>
</tr>
<tr>
<td>8. The house/apartment has a refuge zone, or opening in the roof that enables easy</td>
<td></td>
</tr>
<tr>
<td>evacuation</td>
<td></td>
</tr>
<tr>
<td>9. A pump is installed to pump away water that enters your home</td>
<td></td>
</tr>
<tr>
<td>10. <strong>If you live in a house:</strong> One or more system(s) meant to drain or facilitate</td>
<td></td>
</tr>
<tr>
<td>the outflow of water have been installed. For instance: a drain or a ditch</td>
<td></td>
</tr>
<tr>
<td>11. <strong>If you have a cellar:</strong> The walls and the equipment (doors, isolation, woodwork) of the cellar are made of materials resistant to water</td>
<td></td>
</tr>
<tr>
<td>12. <strong>If you have a cellar:</strong> The floor of the cellar is made of materials resistant to water, such as tiles</td>
<td></td>
</tr>
<tr>
<td>13. <strong>If you have a cellar:</strong> In the cellar, the power sockets are above the most likely flood level</td>
<td></td>
</tr>
<tr>
<td>If you have taken other measures, please specify:</td>
<td></td>
</tr>
</tbody>
</table>

Q20. **If you have been flooded:** Did you implement some of these measures following your (last) flood? If yes, please specify which ones.

□ Yes, numbers: .................................................................

□ No
Q21. How do you rate the following aspects of the structural measures listed above? They...

<table>
<thead>
<tr>
<th>Easiness</th>
<th>Time</th>
<th>Cost</th>
<th>Effectiveness</th>
<th>Usefulness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are very easy to implement</td>
<td>Take a very short time to be carried out</td>
<td>Are very cheap</td>
<td>Are very effective</td>
<td>Seem very useful</td>
</tr>
<tr>
<td>Easy</td>
<td>Short time</td>
<td>Cheap</td>
<td>Effective</td>
<td>Useful</td>
</tr>
<tr>
<td>Not easy, not difficult</td>
<td>Take not a short, not a long time</td>
<td>Not cheap, not expensive</td>
<td>Not effective, not ineffective</td>
<td>Not useful, not useless</td>
</tr>
<tr>
<td>Difficult</td>
<td>Long time</td>
<td>Expensive</td>
<td>Not effective</td>
<td>Not useful</td>
</tr>
<tr>
<td>Very difficult</td>
<td>Very long time</td>
<td>Very expensive</td>
<td>Not effective at all</td>
<td>Not useful at all</td>
</tr>
</tbody>
</table>

Q22. Do you feel that you or a member of your household has the capacity to implement most of the measures listed?

- Very much able
- Able
- Not able, not unable
- Unable
- Not able at all

Q23. Do you think that these measures hamper or improve the appearance of a home?

- Improve the appearance
- The appearance is not hampered, not improved
- Hamper the appearance

Q24. Do you think that these measures decrease or increase the selling value of a home?

- Increase the value
- The value stays the same
- Decrease the value
Q25. Are these measures implemented in or around your current home?
With “above the most likely flood level”, we mean here “above the most likely water level during a flood”.

<table>
<thead>
<tr>
<th>Non-structural measures</th>
<th>Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 You own sandbags, flood dams or panels that can be used to prevent water from entering your home</td>
<td>Yes</td>
</tr>
<tr>
<td>2 The following electrical equipment is above the most likely flood level or on an upper floor:</td>
<td></td>
</tr>
<tr>
<td>– The boiler / heater</td>
<td></td>
</tr>
<tr>
<td>– The washing machine / dryer</td>
<td></td>
</tr>
<tr>
<td>3 In the flood-prone parts of your home, the furniture was chosen and placed to avoid flood damage</td>
<td></td>
</tr>
<tr>
<td>4 Your personal and important documents are stored above the most likely flood level, or on an upper floor</td>
<td></td>
</tr>
<tr>
<td>5 With the other members of the household a “family plan” has been made to know how to cope with flooding</td>
<td></td>
</tr>
<tr>
<td>6 If you have a pump: The pump is maintained, or checked, regularly (every one or two years)</td>
<td></td>
</tr>
<tr>
<td>7 If you have or had an oil tank: You anchored or got rid of the oil tank</td>
<td></td>
</tr>
<tr>
<td>If you have taken other measures, please specify:</td>
<td></td>
</tr>
</tbody>
</table>

Q26. If you have been flooded: Did you implement some of these measures following your (last) flood? If yes, please specify which ones.

□ Yes, numbers: ...........................................................................................................

□ No

Q27. Do you rate the following aspects of the non-structural measures listed above? They...

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easiness</td>
<td>Time</td>
<td>Cost</td>
<td>Effectiveness</td>
<td>Usefulness</td>
</tr>
<tr>
<td>Are very easy to implement</td>
<td>Take a very short time to be carried out</td>
<td>Are very cheap</td>
<td>Are very effective</td>
<td>Seem very useful</td>
</tr>
<tr>
<td>Easy</td>
<td>Short time</td>
<td>Cheap</td>
<td>Effective</td>
<td>Useful</td>
</tr>
<tr>
<td>Not easy, not difficult</td>
<td>Take not a short, not a long time</td>
<td>Not cheap, not expensive</td>
<td>Not effective, not ineffective</td>
<td>Not useful, not useless</td>
</tr>
<tr>
<td>Difficult</td>
<td>Long time</td>
<td>Expensive</td>
<td>Not effective</td>
<td>Not useful</td>
</tr>
<tr>
<td>Very difficult</td>
<td>Very long time</td>
<td>Very expensive</td>
<td>Not effective at all</td>
<td>Not useful at all</td>
</tr>
</tbody>
</table>
Q28. Do you feel that you or a member of your household has the capacity to implement most of
the measures listed?
□ Very much able □ Able □ Not able, not unable □ Unable
□ Not able at all
*Remark:* If none of the measures listed in Q19 and Q25 are implemented in or around your home,
go to Q31.

Q29. How did you pay for these measures (*multiple answers are possible*)?
□ With a compensation □ With a subsidy □ With your own funds
□ You did not pay for these measures yourself
□ Other: .................................................................

Q30. Were you obliged or strongly stimulated to take these measures by (*multiple answers are possible*)…
□ Your town (includes the compulsory measures from the PPRi, risk prevention plans for floods,
of your town)
□ Your insurer
□ Other

Q31. Did some of your close friends, relatives or neighbours take some measures to protect their
homes against flooding?
□ Yes □ No □ I do not know

Q32. In the coming future, do you expect to take (additional) measures, such as the ones listed
previously, to protect your home?
□ Certainly □ Probably □ I do not know □ Probably not
□ Certainly not
E – YOUR PERSONAL SITUATION

Q33. Are you…
□ Male
□ Female

Q34. In which year were you born? /_/_/_/_/

Q35. Are you…
□ Single □ In a relationship □ PACSed □ Married □ Divorced
□ Widowed

Q36. How many people live in your home, including yourself? /_/_/ People

Q37. How many children or dependent people live in your household? /_/_/ Children or dependent people

Q38. Are you… □ Tenant □ Owner … of your home?

Q38.1. To homeowners:
What is the current market value (or if you experienced a flood in 2010 or 2011, the market value before the flood) of your home, according to the following ranges?
□ Below 100,000 Euros
□ Between 100,001 and 150,000 Euros
□ Between 150,001 and 200,000 Euros
□ Between 200,001 and 300,000 Euros
□ Between 300,001 and 500,000 Euros
□ More than 500,000 Euros
If you have experienced a flood in this home, you indicated the:
□ Current market value □ Market value before the flood

Q39. How much is the total current value of all the contents in your home, according to the following ranges?
□ Below 25,000 Euros
□ Between 25,001 and 50,000 Euros
□ Between 50,001 and 75,000 Euros
□ Between 75,001 and 100,000 Euros
□ Between 100,001 and 150,000 Euros
□ More than 150,000 Euros
Q40. In what year was your home built? / / / / /

Q41. For how long have you been living in this home? Cross your answer among the ones available.
   / / / Days / Weeks / Months / Years (encircle your answer)

Q42. For how long do you still expect to stay in this home?
   □ / / / Days / Weeks / Months / Years (encircle your answer)
   □ Always / for the rest of my life
   □ I / we do not wish to stay but do not leave for the moment for financial reasons

Q43. You are...
   □ Farmer
   □ Craftsman, trader, business manager
   □ Liberal profession
   □ Executive, intellectual profession
   □ Employee
   □ Worker
   □ Retired
   □ Student
   □ Other without profession (unemployed, housewife, etc.)

Q44. What is your highest completed education level?
   □ No diploma
   □ CEP
   □ BEPC
   □ CAP ou BEP
   □ Bac ou brevet professionnel
   □ Bac +2 = IUT/BTS/DEUG
   □ Bac +3 et +4 = Licence/Maitrise
   □ Bac + 5 et + = Ingénieur/Master/Doctorat

Q45. What is the monthly net income of your household, among the following categories:
   □ Below 1,000 Euros per month
   □ Between 1,000 and 1,500 Euros
   □ Between 1,501 and 2,000 Euros
   □ Between 2,001 and 2,500 Euros
   □ Between 2,501 and 3,000 Euros
   □ Between 3,001 and 4,000 Euros
Flood damage mitigation investments

☐ Between 4,001 and 5,000 Euros
☐ Between 5,001 and 7,500 Euros
☐ More than 7,500 Euros

Do you have remarks on the questionnaire or the themes tackled in this questionnaire?

..........................................................
..........................................................
..........................................................
..........................................................
..........................................................
..........................................................
..........................................................
..........................................................

Thank you very much for your time and your participation.