

## **Summary:**

### **Introduction**

Despite the considerable efforts to reduce the risk of natural disasters, floods remain the most frequent and devastating natural hazard worldwide (World Bank 2012). In the future, flood risk is projected to further increase in many regions as a result of two complementary trends. On the one hand, flood hazards are expected to become more frequent and more severe owing to the effects of climate change on water resources (IPCC, 2007; te Linde et al. 2010). On the other hand, the ongoing increased concentration of people and economic assets in flood-prone areas is leading to a growing exposure to floods.

Just as flood risk is continuously changing due to the projected effects of climate change on water resources and increases in exposure, flood risk management is also constantly in a state of flux and needs to be adapted to a changing environment (Bubeck et al. 2012c). Flood management in Europe and on a global level has increasingly shifted to integrated risk management approaches, including measures that reduce damage and exposure (de Moel et al. 2009; Büchele et al. 2006). Nowadays, the contribution of private households to damage reduction by means of flood mitigation measures, such as mobile flood barriers or flood-adapted building use has become an important component of integrated flood-risk management strategies in many countries (Bubeck et al. 2012c).

### **Objective and research questions**

This thesis examines the contribution that private flood mitigation measures can make to a changing risk and risk management environment in terms of their damage-reducing potential and their level of implementation. This is done by analysing the following multidisciplinary research questions:

- 1 What changes in flood risk can we expect in the coming decades, and what are the independent contributions of climate change and increases in exposure to these developments?
- 2 How uncertain are flood damage projections with respect to the application of different flood damage models?
- 3 How did flood damage mitigation measures implemented by private households develop over time, and what was the damage-reducing effect of these measures during past flood events?
- 4 What is the relation between flood risk perceptions, the mitigation behaviour of flood-prone residents and their demand for governmental risk reduction?
- 5 Which factors, other than risk perceptions, influence flood mitigation behaviour, and, in particular, what is the influence of the different components of flood-coping appraisals on the latter?
- 6 Can we identify environmental factors, drivers, and feedback mechanisms that can explain why countries opt for different flood-risk management portfolios?

## **Research findings**

**Changes in future flood risk, the independent contributions of climate change and increasing exposure, and the uncertainties associated with these developments:** The risk from extreme flood events along the Rhine might increase considerably by between 53 and 230 per cent during the coming decades. The main driver of the future increase in risk from extreme events is climate change: in particular increased precipitation and snowmelt are expected to increase flood probabilities. But the effects of socio-economic developments will also make an important contribution to the future risk increase through further concentration of people and economic assets in flood-prone areas. Moreover, it was shown that the uncertainties associated with possible future developments, which are reflected in the diverging climate and socio-economic scenarios, remain large. In addition to the uncertainties resulting from diverging future scenarios, the application of different damage models introduces further uncertainties, especially in terms of estimates of absolute damage values (by a factor of 3.5 to 3.8). However, estimates of relative changes in flood damage developments prove to be more consistent between models and differ by a factor of 1.4.

**Long-term development, current implementation level, and the damage-reducing effect of private flood mitigation measures:** Data from flood-prone households living along the German part of the river Rhine show that households' direct disaster experience is an important trigger for the implementation of flood mitigation measures. A significantly increased rate of implementation of private flood mitigation measures can be consistently observed in the aftermath of flood events between 1980 and 2011. For instance, the number of implemented flood mitigation measures more than doubled in the aftermath of the severe flood in 1993. The damage-reducing effect of flood mitigation measures was examined by comparing the precautionary behaviour of and damage suffered by households that were affected by two severe floods in 1993 and 1995 along the Rhine. This comparison demonstrated that the damage reduction of more than 50 per cent in 1995 compared with 1993 can indeed be attributed to an improved preparedness of the flood-prone population. Moreover, it is found that even respondents who did not undertake any precautionary measure themselves in 1993 and 1995, still benefitted from the improved preparedness of others because the contamination of flood waters was reduced.

**Relationship between flood risk perceptions, mitigation behaviour and the demand for governmental risk reduction:** Since risk perceptions have dominated the literature on flood mitigation behaviour, and because risk- awareness raising is an important element of current and envisaged flood risk management, it is imperative to understand the role that risk perceptions play in prompting private precautionary behaviour. A review of 16 peer-reviewed studies which together examined the relation between flood risk perceptions and mitigation behaviour among 12,000 respondents in 7 countries indicates that high risk perceptions do not necessarily result in improved mitigation behaviour, as is often suggested. The majority of these studies report no or only a weak relationship between risk perceptions and flood mitigation behaviour. The weak relationship between flood risk perceptions and precautionary behaviour is further supported by a survey among flood-prone households in central Vietnam, which shows that flood risk perceptions are a rather weak predictor of intentions to undertake flood mitigation measures. Moreover, the study in Vietnam confirms that the demand for governmental flood risk reduction cannot be generally derived from individual risk perceptions, but a specific component of it: namely, the perceived consequence of flooding. The fact that the results obtained in Vietnam are comparable to studies conducted in Europe and the US indicates that insights can be transferred cross-culturally.

**Flood-coping appraisals and other factors than risk perceptions that influence flood mitigation behaviour:** Given the finding that flood risk perceptions, as such, are a rather weak predictor of flood precautionary behaviour, it is of interest to understand what other factors are found to be consistently related to flood mitigation behaviour. A factor that received considerably less attention in the literature examining this aspect is flood-coping appraisals, even though the few existing studies on this topic indicated a consistent relation with precautionary behaviour. The survey conducted among 752 flood-prone households along the river Rhine confirms that flood-coping appraisals are important variables of influence on four different types of flood mitigation behaviour. Both response-efficacy and self-efficacy are found to considerably influence flood mitigation behaviour. Moreover, it is shown that, in addition to flood experience, the level of income plays an important role as far as the implementation of expensive structural mitigation measures is concerned. Furthermore, the social environment, which captures whether neighbours or friends also undertook a flood mitigation measure, is of significant influence on the four different types of flood mitigation behaviour. A negative influence on flood precautionary behaviour is found for non-protective responses. While non-protective responses, such as wishful thinking, postponement or denial, do not actually reduce the risk of flooding that respondents face, they help to avoid or suppress the negative emotions associated with high risk perceptions.

**Environmental factors, drivers and feedback mechanisms that can explain differences in adopted flood-risk management portfolios:** While there is a general trend towards integrated flood-risk management concepts in Europe and other regions, the initial situation in the various countries, as well as the pace and direction of change varies significantly between countries. A conceptual framework is presented that draws insights from a range of policy science concepts in an integrated way, in order to explain differences between countries in terms of the adopted flood-risk management portfolio, and in terms of the changes to these systems. Four case studies (the Netherlands, Germany, the UK and the USA) are used to provide an overview of factors and possible feedback mechanisms that influence flood-risk management practices in the different countries. These include, amongst other factors, geographical boundary conditions, the occurrence of flood-focusing events, the efficiency of the existing flood risk management system, but also changes in human behavioural factors. For instance, countries which face a flood hazard that is characterized by a low probability but high impacts, and by a short warning time (geographical boundary conditions), employ higher safety standards and thus more strongly rely on structural portfolios. Moreover, the occurrence of large-scale flood-focusing events also often creates a strong demand to alter course in flood risk management.

### **Implications for integrated flood risk management:**

This thesis demonstrated that, increasing the level of flood mitigation measures at the household level, can be viable strategy in flood risk management. It is shown that flood-prone households have considerably contributed to damage reduction, and could thus contribute to integrated flood risk management in the present and – and potentially can increase their contribution in the future.

According to the projected effects of climate change, floods will become more frequent and more extreme in many regions, and, could increasingly affect areas with little prior flood experience. This also implies that highly vulnerable areas will be increasingly affected. Given the finding that a large share of households that currently live in highly flood-prone areas have not undertaken any precautionary measure, further efforts are needed to reach a higher level of precautionary measures.

A first important step in this direction would be to overcome the existing lack of knowledge and lack of support of flood-prone households regarding their increased responsibility to contribute to private flood damage reduction.

However, although it is obvious that people need first to be aware of a certain risk in order to possibly react to it, the findings of the present thesis indicate that the predominant focus on risk awareness (or perception) will not be sufficient to manage the intended transition to more integrated flood management approaches. Moreover, it is suggested that a sole focus on risk-awareness raising can potentially even lead to non-protective responses, such as fatalism, denial, and wishful thinking. Given the important role that flood-coping appraisals, and in particular self-efficacy and response-efficacy, play in translating high risk perceptions into protective behaviour, these aspects should receive greater attention in risk communication policies and future research on flood-mitigation behaviour. Risk communications should therefore emphasize that flood mitigation measures at the household level can effectively prevent or reduce flood damage. Moreover, practical advice should be provided to households on how to deploy such measures.

Given the strong influence of flood experience on the precautionary behaviour of flood-prone households, additional policies that go beyond purely voluntary agreements seem unavoidable if an adequate level of preparedness is to be reached, including in areas with little prior flood experiences. The finding that flood mitigation measures are often appraised positively, but are postponed as long as they are not considered as absolutely necessary by the respondents, shows that there is scope for alternative policies to overcome this passiveness in order to increase the preparedness of people of risk. These policies should not only apply to current flood zones in the Rhine basin (e.g. the 1/100 year flood zone) but should anticipate the effects of climate change on these flood zones. For instance, long-term flood insurance policies could provide financial incentives for households that implement appropriate measures, by granting premium reductions, or, by providing practical advice in terms of their implementation (self-efficacy). The findings of this thesis show that this potential is currently unexploited by German insurers. Another approach to overcome the low-level of preparedness of flood-prone households would be to integrate more stringent requirements in existing building codes, and to enforce these more strictly.