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ORIGINAL ARTICLE

A review of damage-reducing measures to manage fluvial flood risks in a changing climate

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Abstract Damage due to floods has increased during the last few decades, and further increases are expected in several regions due to climate change and growing vulnerability. To address the projected increase in flood risk, a combination of structural and non-structural flood risk mitigation measures is considered as a promising adaptation strategy. Such a combination takes into account that flood defence systems may fail, and prepares for unexpected crisis situations via land-use planning and private damage reduction, e.g. via building precautionary measures, and disaster response. However, knowledge about damage-reducing measures is scarce and often fragmented since based on case studies. For instance, it is believed that private precautionary measures, like shielding with water shutters or building fortification, are especially effective in areas with frequent flood events and low flood water levels. However, some of these measures showed a significant damage-reducing effect also during the extreme flood event in 2002 in Germany. This review analyses potentials of land-use planning and private flood precautionary measures as components of adaptation strategies for global change. Focus is on their implementation, their damage-reducing effects and their potential contribution to address projected changes in flood risk, particularly in developed countries.

Keywords Climate adaptation · Land-use planning · Damage reduction · Precaution · Risk zoning · Flood

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1 Introduction

Flood damage in Europe and worldwide has increased considerably in recent decades, particularly due to an on-going accumulation of people and economic assets in risk-prone areas (Barredo 2009; Merz et al. 2012). Examples of particularly damaging floods are the following: The large-scale flood event in June 2013 in the Elbe and Danube catchments caused losses of around €10 billion in Germany (Munich Re 2014). A special reconstruction aid fund of €8 billion has been implemented by the federal states and the German federal government (the so-called 'Aufbauhilfegesetz' came into effect 19th July 2013). The 2013 flood is comparable in respect of region affected, intensity and damage to the extreme summer flood in 2002 (Becker and Grünewald 2003), which caused damage of €11.6 billion in Germany (Thieken et al. 2007). It is expected that flood risk will continue to rise in many regions due to a combination of climate change and an increase in vulnerability (Kundzewicz et al. 2005, 2013), e.g. due to increasing flood plain occupancy, value increase in flood-prone areas and changes in the terrestrial system, e.g. land cover changes and river regulation. For instance, winter discharges and consequently flood probabilities along the Rhine are expected to increase in coming decades (Te Linde et al. 2011).

Against the background of the projected increases in flood risk due to the effects of climate change, growing exposure and possibly increased susceptibility, as well as the considerable uncertainties associated with these developments, flood risk management has increasingly shifted towards more integrated and adaptive flood risk management strategies in many European countries and worldwide in recent decades (Bubeck et al. 2014; Kreibich et al. 2014b). The European Flood Directive on the assessment and management of flood risks (European Commission 2007) demands the development of management plans for areas with significant flood risk, which will be integrated in the long term with the river basin management plans of the Water Framework Directive (European Commission 2000) contributing to integrated water management on the scale of river catchments. For instance, even The Netherlands, which long-time focussed solely on structural flood defences recently started to consider flood damage reduction measures as a complementary option, especially for areas that are not protected by the dike ring system (Bubeck et al. 2014; Van Vliet and Aerts 2014). A new policy framework has been adopted named Multi-layer Safety (MLS), which takes a risk-based flood management approach (Ministry of Transport and Water et al. 2009). This framework addresses three layers: (i) prevention, (ii) damage reduction through sustainable spatial planning and (iii) crisis control and evacuation.

Theoretical basis is commonly the risk management cycle (e.g. DKKV 2003; PLANAT 2004; Kreibich et al. 2014a, b), which integrates risk reduction and response in the following consecutive phases: (1) emergency response, (2) recovery and reconstruction, (3) event and risk analysis and (4) preparedness. Before, during and shortly after an event, emergency measures are undertaken to mitigate losses. During the recovery phase, damage is repaired and society tries to regain a similar or preferably a better standard as before the event happened. Improvements in preparedness should be based on event and risk analyses. Preparedness consist of prevention, which aims to avoid damage primarily by an appropriate land-use or structural measures; of preparation, which strives to respond and cope with the catastrophe; and of precaution, which wants to reduce damage mainly due to private precautionary measures (Kreibich et al. 2005a). An important feature of the risk management cycle is the continuous iterative process relying on risk monitoring and adaptive management to increase resilience (Kreibich et al. 2014a). Olsson et al. (2004) suggest adaptive co-management, which means approaching the institutional and organisational landscape as carefully as the ecological one (Kinzig 2001; Berkes et al. 2003), to enhance the resilience of social–

ecological systems and make them more robust to change. This approach allows managers to learn and to actively adapt ecosystem management policies and reduces the risk of entering unsustainable and undesirable development trajectories.

Maybe the most straightforward solution to reduce flood risk is to avoid (the most) dangerous places in the first place so little to no harm can come to human life and property. Historically, this was in essence the very first flood management measure employed by civilisation. Looking at early human settlements, they are in many cases founded on elevated grounds like outcrops of bedrock, moraines or river dunes (Stalenberg and Vrijling 2006). However, with increasing population pressure and due to the benefits associated with settling close to river courses (Kummu et al. 2011), towns expanded considerably, forcing the occupation of ever more dangerous lands, a process that continues until today (De Moel et al. 2011). This expansion into flood-prone areas has given rise to the development of extensive flood defence systems. While generally reducing the flood risk, the construction of levees can, paradoxally, also increase flood risks in that it promotes new developments, which increase the potential damage a flood would cause in case of a defence failure, which is known as the levee effect (see e.g. Pielke 1999; Di Baldassarre et al. 2009; Lane et al. 2011). Therefore, spatial planning is an important tool to manage flood risks and is part of the portfolio in various countries, supplementing flood defence structures (Burby et al. 1999; APFM 2007; Neuvel and Van den Brink 2009; Glavovic 2010).

Where villages or towns already exist in flood-prone areas, flood damage must be kept as small as possible. Previous studies have indicated that flood-damage-reducing measures adopted by private households or companies, such as flood-adapted building use, the deployment of mobile flood barriers or securing of contamination sources, can effectively reduce damage (e.g. Kreibich et al. 2007, 2011b, 2012; Olfert and Schanze 2008; Holub and Fuchs 2008). Accordingly, private contribution to damage and thus risk reduction has become an important component of contemporary flood risk management portfolios in many countries (Bubeck et al. 2014). In Germany, for instance, the responsibility of flood-prone residents and companies to contribute to damage reduction gained prominence following major flood disasters along the river Rhine in 1993 and 1995 (Federal Environment Agency 2010). The disastrous floods along the River Elbe and the River Danube in 2002 again revealed significant regulation and implementation deficits in terms of damage reduction (Federal Environment Agency 2010; Petrow et al. 2006). As a result, the national framework law was revised to provide more stringent and uniform regulations in terms of spatial planning and damage reduction by households and companies (Wasserhaushaltsgesetz 2009). Since 2009, everybody endangered by flooding is obliged to undertake appropriate, reasonable actions to reduce flood impacts and damage (Wasserhaushaltsgesetz 2009).

Even though the contribution of land-use planning and private damage reduction have become an important component of many contemporary flood risk management portfolios, knowledge remains scarce, confined to specific regions or case studies and is hardly generalisable. Efficient strategies in the European context may hardly be directly transferable to developing countries. For instance, formal flood mitigation strategies adopted by authorities often do not reduce risks for people living in informal settlements (Wisner 1998; Chatterjee 2010). In addition to risk management, urban planners should develop means of reducing the division between slum population and mainstream urban population via addressing issues like land ownership or affordable housing in megacities (Chatterjee 2010). However, this problem area is not in the focus of this paper.

The objective of this review is to analyse the potential of flood-damage-reducing measures, i.e. land-use planning and private precautionary measures as components of adaptation strategies at local, regional and national scales. Focus is on their implementation, their damage-reducing effects and their potential contribution to address projected changes in flood risk, particularly in developed countries where most research on these topics has been undertaken so far.

2 The governance context of flood management

Institutional settings and policy frameworks regarding flood risk management differ considerably between countries because of different underlying political philosophies. A major normative question underlying flood policies is whether the government is responsible for protecting its civilians from floods, or that civilians (also) have the responsibility to take actions to protect themselves. According to limited rights theories (e.g. libertarianism), the state should guarantee safety and peace, but leave the rest to people to decide themselves (Keessen et al. 2013). In liberalism, the state should provide its citizens with the space and opportunities to lead worthwhile lives (Rawls 1973). People should have the opportunity to live in areas that are safe but also have the right to live somewhere else. Private parties will have an important role in flood management. Some might argue that this can increase resilience, as private parties tend to be more flexible and innovative than governments. Utilitarians look whether an action contributes to greatest happiness for the largest amount of people. Decisions should be based on cost–benefit analysis (Alexander 2002). Collectivist approaches advocate that actions should be taken to ensure equal opportunities and outcomes for all (Cohen 2000).

Of course, in most countries, different groups support different political philosophies (Keessen et al. 2013), but often one dominates. In more liberalism-oriented countries such as the United States and Canada, for instance, we see a smaller federal involvement in flood management and larger private responsibilities. Utilitarian countries will look for measures that are most cost effective; depending on the physical situation, this can either be public or private measures. In countries with a collectivist approach, the government takes care of flood management and uses measures that provide the same level of safety to all inhabitants and are more oriented towards solidarity.

In most countries, there is at least some level of involvement of the national government, which sets overall goals. These goals are than implemented by lower governments. The level of federal/national involvement, however, differs considerable between countries. Where national involvement is stronger, the processes are more formal, to make sure that lower governments follow national guidelines. In The Netherlands, for instance, flood management is strongly state centred, and the Dutch Water law stipulates detailed norms for primary embankments and strict guidelines for their maintenance. In Canada, flood management is more diffuse and more levels of government are involved. Local government has the largest role there, whilst the federal government is only involved in flood recovery.

In most countries, private parties are involved to some extent. The level of responsibility, however, differs. In several countries, flood insurance does not exist (Canada, The Netherlands), whilst in other countries, insurance is either voluntary (Germany) or compulsory (US, France). In most countries, homeowners are made aware of flood risks and required to take action themselves; in France, local governments are required to inform the public at least every 2 years (Fleischhauer 2005). Recent studies have shown that awareness alone is, however, not enough and that private action depends strongly on the coping appraisal of individuals (Bubeck et al. 2012a).

Also interesting is the difference in definition of what flood prevention constitutes of. In The Netherlands, flood prevention equals embankments, but in many other countries, the main flood prevention strategy relates to anti-floodplain encroachment policies (e.g. France and United Kingdom; Pottier et al. 2005). Several countries (e.g. France and Canada) explicitly give priority to non-structural measures over structural measures, whilst others (e.g. The Netherlands) focus much more on structural measures. France has even decided to remove over 1500 houses in the areas affected by the 2010 storm surge, in order to minimise flood damage if such a flood would occur again and aims to develop a law that forbids the construction of new embankments that allow new areas to be developed (Lumbroso and Vinet 2011). Such a law would be unthinkable in The Netherlands, showing the large differences in normative viewpoints even within Western Europe.

In most countries, we see a move towards more integrated flood risk management approaches. Japan, for instance, is combining structural measures (‘super levees’; very wide levees that might overtop, but are very unlikely to breach) with non-structural measures like flood zoning and evacuation policies. Canada is increasing its focus on flood defence, whilst The Netherlands is increasing its focus on dealing with flood consequences. Up to 2004 in the United Kindom’s England and Wales, a flood defence paradigm dominated, but this has been changing in more recent year to a more sustainable flood-risk management paradigm. Climate change projections triggered this change, as studies showed it makes the defense approach unsustainable and unaffordable in the long term (Evans et al. 2004; DEFRA 2005). The large floods of July 2007 in UK and the subsequent Pitt Review (Cabinet Office 2008) have further triggered the development of new flood-risk legislation that aim to be more resilient (Graham et al. 2012; Ball et al. 2013). This more integrated approach connects domains related to flood risk management, such as land-use planning, disaster response, and building codes. In countries that already have a more integrated approach, we see that these fields are indeed often interlinked: often building requirements are part of flood zoning. Often, local governments have an important role in the detailed flood zoning plans, as they have the best local knowledge. This makes it possible to fine-tune higher level regulations to match the specific circumstances of the area. On the other hand, it also makes the process vulnerable, as there are often other short-term interests and benefits of new developments.

3 Land-use planning

3.1 Flood hazard mapping and zoning

Taking action to avoid dangerous areas, or implementing adequate measures to protect society in these areas, starts with the identification of such areas. This is commonly referred to hazard mapping. Hazard mapping is common in many places. For instance, De Moel et al. (2009) illustrate that as good as all European countries have flood hazard maps available, or are in the process of producing them to comply with the European flood directive. General methodologies for flood hazard mapping are detailed by Merz et al. (2007) and De Moel et al. (2009). Most commonly, flood hazard mapping involves the determination of flood extents for synthetic events with a specific return period (i.e. the 100-year flood zone). There are, however, more indicators for the severity of a flood besides flood extent, such as flood depth, flow velocity, and rate of rising of the water (De Moel et al. 2009), which can also be mapped. In practice, flood extent and depth are the most common ones used (Fig. 1): flood extent because it allows depicting events with various intensities in a single map, and flooding depth because it is the most important parameter influencing flood damage (see, e.g. Smith 1994; Kreibich et al. 2009a; Merz et al. 2010).

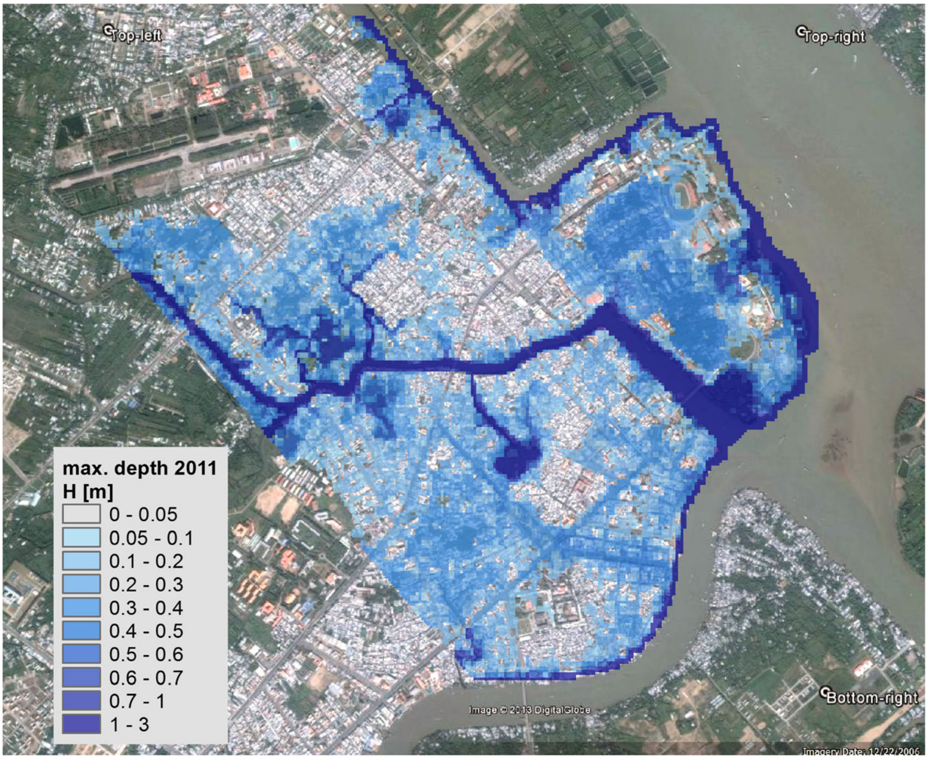

Fig. 1 Example of a flood extent and water depth map: simulated maximum water depth of the 2011 Mekong flood in Can Tho, Vietnam (Apel et al. 2014, manuscript in preparation)

In some cases, several indicators for the severity of a flood are combined into distinct danger classes. These different classes are then used for zoning, as done in Switzerland (Zimmerman et al. 2005). For The Netherlands, De Bruijn and Klijn (2009) created a hazard rating map, which was a combination of the design level of the defence, the rate at which the water table rises and the resulting water depth. All three factors were scaled between 0 and 1 and averaged to get the combined hazard rating (De Bruijn and Klijn 2009). Another hazard indicator is local individual risk (Pieterse et al. 2013). It is defined as the annual probability that a virtual person dies as a result of a flood in a specific location. Local individual risk aggregates flood events with different probabilities, using water depth, the rate the water table rises and the effect of evacuation to estimate the probability of floods causing a fatality (Beckers and De Bruijn 2011).

Hazard maps form the basis for integrating flood considerations into spatial planning policy to reduce flood risk. The visualisation and communication of such maps is important in determining whether they are used successfully and adequately (Fuchs et al. 2009; Meyer et al. 2012). For instance, maps should contain a limited amount of components and classes, with a legend that is sufficiently large. Maps should be tailored for different audiences like strategic planners, emergency managers or general public (Meyer et al. 2012). Participative workshops using interactive (mapping) tools can help in getting the information across (Eikelboom and Janssen 2013; Arciniegas et al. 2013) and making actors familiar with the maps.

Zoning policies rely heavily on the detail and quality of hazard maps defining different zones. This can lead to various complications. For instance, the production of detailed hazard maps can cause delays in the implementation process of a policy. Furthermore, the creation of hazard maps can become a politicised effort, where local communities have an interest in underestimating the hazard (Fleischhauer 2005). Updating maps is important in this regard as well, but is not often prioritised. This has been recognised as a problem in the US by Burby (2001), and became painfully obvious when Sandy hit the northeast coast in 2012. Updated maps where released shortly after Sandy, which showed a substantial increase in flood-prone area compared to the old maps developed over 25 years earlier.[1] Similar problems were experienced along the Lower Fraser river in Canada, where recent model results showed that flood levels would be much higher than expected from the old 1968 flood maps (Fraser Basin Council (and Northwest Hydraulic Consultants Ltd) (2006)).

The development of maps does not automatically lead to good flood zoning: Shrubsole (2007) and Benoît et al. (2003) showed that the development and the publication of flood hazard maps had no effect on the decision about building in flood-prone areas and the development of the damage potential in several Canadian regions.

3.2 Flood risk reduction via land-use planning

The contribution of spatial planning towards the reduction of flood risk can take many forms. In its most extreme form, spatial planning policies can be aimed at removing people and assets from existing flood-prone areas. For instance, after the 1993 floods in the Mississippi, a buyout program was set up, which led to the acquisition of 7700 floodplain properties in Missouri and Illinois (Pinter 2005). An even more striking example can be found in China, where the Return Land to Lake Program resulted in the moving of 815,000 inhabitants and a loss of 900 thousand hectares of farmland to increase the surface area of Dongting Lake from 2680 to 4350 km^2 in order to prevent flooding (Li et al. 2007).

Perhaps, the most obvious way, however, is to implement zoning regulations. This entails the determination of areas with a certain flood risk (i.e. the 100-year flood zone) and setting up certain land-use requirements for these zones. Such requirements could constitute, for instance, a complete ban, restricting certain uses, requiring certain building standards, giving recommendations and providing information to inhabitants in certain zones (Merz et al. 2007).

Zoning is used in various countries to manage flood risks. Under the Canadian Flood Damage Reduction Program—FDRP from 1975 to 1999, floodplains in 900 communities were mapped and 320 flood risk areas designated (Fraser Basin Council and Arlington Group 2008). In Germany, the area affected by a 100-year flood plays an important role for flood risk management (Marco 1994; Watt 2000). In this area, land use is often restricted, and most flood defences (e.g. levees, flood retention basins) are designed to protect up to this flood level (Petrow et al. 2006). In France and Switzerland, zoning policies include zones where developments are completely prohibited and zones where there are conditional uses or construction requirements (Fleischhauer 2005; Zimmerman et al. 2005). Switzerland defines four zones depending on the probability and intensity (inundation depth, flow velocity), which range from severe hazard (prohibited zone for construction and development) to residual risk (information) (Egli 2000; BWG 2001). Spain includes spatial planning of flood areas in the Water Act and some of its regulations (Menendez 2000). There are four zones, for which restrictions in land use are given: the channel (10-year flood zone), a restricted-use area, i.e. a 5-m buffer on either side of the channel, a surveillance zone, i.e. a 100-m wide strip on either

[1] http://www.region2coastal.com/faqs/advisory-bfe-faq

side of the channel and a flood risk zone, i.e. with an inundation return period of 500 years. In the first three zones, authorization is required for any kind of construction. Zones that completely ban developments are not always incorporated in zoning policies. In the US and Canada, zoning is linked to building requirements in that they require a certain elevation of the floor level of houses in flood zones. In Canada, these requirements come from the provincial or local level, e.g. provincial guidelines in British Columbia state that the floor of houses should be located above the 1 in 200 years flood level (Ministry of Water Land and Air Protection 2004). In the US, zoning is linked with the National Flood Insurance Program (NFIP), in which many (more than 18,000) communities participate who otherwise are not eligible for federal disaster aid and grants or loans for construction in floodplains (Holway and Burby 1993). The US building standards apply to all new buildings and buildings that are substantially renovated (>50 % of the value of the building) and are directly linked to flood insurance (Aerts and Botzen 2011). In various European countries (e.g. in the UK, Finland) there is an obligation to take flood hazard zones into account somewhere during the spatial planning process without a specific zoning policy (De Moel et al. 2009).

In many countries (e.g. Germany, The Netherlands, UK and Canada), municipalities play an important role in flood risk management as they can specify measures for the minimisation of the damage potential for flood-prone areas in land-use plans (Böhm et al. 2004). Their land-use plans tell which land use is allowed on each plot, and flood issues could, theoretically, be incorporated, but this is not always the case in practice. In The Netherlands, for instance, flood zoning is currently used only in flood plains outside the embankments, with the goal to limit building in order to maintain the rivers' discharge and storage capacity.

Where zoning policies can be used to limit the exposure to flooding of people and assets, spatial planning can theoretically also play a role in limiting fatalities by optimising the possibility to reach safe places in case of flooding, be it within the flooded region (vertical evacuation, for instance to higher floors or designated flood shelters) or out of the affected region (horizontal evacuation). This is apparent in Hamburg (Hafen City), where walkways have been created above extreme flood levels. In addition, spatial planning can facilitate the evacuation of people away from threatened areas by making sure the main road network is elevated and thus able to be used longer in case of flooding. Old levees or local embankments can potentially be used for this and may have an extra compartmentalisation effect (Klijn et al. 2010; Koks et al. 2014). Such compartmentalisation could limit the flood extent and thus fatalities and damage as well.

Theoretically, spatial planning policies thus have a large potential to reduce flood risk by reducing potential consequences. Research on the effectiveness of spatial policies in reducing flood risk, however, shows that it has often failed to stop the encroachment of floodplains. Moreover, such policies mainly target new developments, whilst there is usually already a considerable building stock present.

Pottier et al. (2005) investigated the effect of spatial policies in France, where there is a national system with mandatory risk zones and insuranceand ,in England and Wales, where there is a system based on national guidance and local attention to flooding. They illustrate that, despite existing regulations, in both countries, the pressures on floodplains continue to grow, though the French policies probably lowered the pace of development and construction mainly in the moderate risk areas (Pottier 2000; 2002). In England, the flood-risk advice given by the Environment Agency was often taken into consideration, but many developments still took place in flood-prone areas. Similarly in the US, Holway and Burby (1993) show that the NFIP program has succeeded in reducing flood losses through the elevation of buildings, but had little effect on the rate of floodplain development. If there is not a clear penalty to non-compliance, there is a potential that rules are simply not followed as has been illustrated, e.g. in Poland (Wanczura 2005).

While reducing flood risk and limiting floodplain encroachment make sense from a risk management point of view, the larger context should always be kept in mind. The benefits of developing flood-prone areas to society may outweigh the increase in average annual damage or other costs (Green et al. 2000). Additionally, implementation of zoning regulations may also have negative effects. For instance, stringent policies on building codes and rigid enforcement may hamper urban rehabilitation, as has been shown in New Jersey (Burby et al. 2006).

Whilst spatial planning can play a role in limiting the consequences of flood events, it can also play a role in limiting the flood hazard. In the last couple of decades, the philosophy of giving space back to rivers in order to reduce peak water levels has gained quite some traction, for instance in The Netherlands (Ministry of Transport Public Works and Water Management 2006; Ministry of Infrastructure and the Environment 2011), UK (DEFRA 2005), USA (Cho 2011), Belgium (Sigmaplan 2014) and France (Erdlenbruch et al. 2009). In such an approach, spatial planning is used to increase storage space or through flow of the river, reducing water levels for a given amount of discharge. Measures include, for instance, relocating dykes, lowering floodplains, deepening channels, using retention areas or creating bypasses (Hooijer et al. 2004).

Given the spatial dimension of such activities, they very often have an integrative character, both spatially (up–downstream), sectoral (nature, agriculture, housing) and thematically (hazard reduction, damage reduction, prevention). As such, they fit well with contemporary paradigms like integrated water resource management, catchment management, building with nature and so on. Especially redevelopment of nature areas is often coupled in this context, which is an explicit goal of programs like the Sigmaplan (Belgium), Plan Ground Loire Nature (France), or Room for Rivers (The Netherlands). In all these programs, but also programs without a particular nature focus like the PAPI programmes in France (Erdlenbruch et al. 2009), spatial measures to reduce flood levels or consequences are part of a package that also includes various protection measures. This shows that flood management is becoming more and more integrative in many places.

4 Private flood damage reduction

4.1 Implementation of private damage-reducing measures

Where settlements already exist in flood prone areas, private precautionary measures can reduce flood damage. Private households and companies can undertake various damage-reducing measures: These include precautionary measures taken in and around exposed buildings as well as preparatory measures such as collecting information about flood risk and flood protection or participation in neighbourhood help in order to enable a more effective reaction in case of an event. Particularly, building precautionary measures reduce damage in flood-prone areas (ICPR 2002; ABI 2003; Kreibich et al. 2005a). Building precautionary measures aim at minimising damage by means of flood-adapted use and equipment of buildings, i.e. wet flood proofing or by means of sealing, reinforcement and shielding, i.e. dry flood proofing (ICPR 2002). Examples of wet flood proofing are the following: to adapt the building use, which means that cellars and endangered storeys are not used cost intensively; to adapt the interior fitting which means that in endangered storeys, only waterproofed building material and movable small interior decoration and furniture are used; or to safeguard possible sources of contamination, such as an oil tank of a heating system. For instance, in Germany, the federal states have laws stipulating that oil heating systems, including oil tanks, have to be flood-proofed within flood prone areas (e.g. VAwS-Baden-Württemberg 2005; VAwS-Hessen 2006; VAwS-Bayern 2008). Dry flood proofing measures include, for instance, to adapt the building structure, e.g. via an elevated configuration; to waterproof seal the cellar, e.g. by constructing the basis and walls of buildings out of concrete that is non-permeable; or to deploy mobile flood barriers such as temporary flood guards. When new houses or even settlements are being built or extensively renovated, an elevated configuration or the construction of buildings without cellars should be considered. Other private precautionary measures are described in Holub and Hübl (2008).

Information material promoting private precautionary measures have been published, amongst others, by several German ministries and cities (BMVBW 2002; MURL 2000; MUF 1998; Stadt Köln 1994), the UK Environment Agency (Environment Agency 2003a, b; Hampshire Flood Steering Group 2002; SEPA 2003), the US Federal Emergency Management Agency (FEMA) and Army Corps of Engineers (USACE) (FEMA 1998a, b, 1999; USACE 1995; 1996), by Japanese municipalities (OECD 2006) and in Australia (DECC-NSW 2008). Some governments might, however, be hesitant to communicate flood risks out of fear to negatively affect the investment climate.

Taking precautionary measures often demands self-reliant behaviour on behalf of the private households or companies since most measures are voluntary (Heiland 2002). Raschky (2008) highlights the effects of the institutional framework on human behaviour and the incentives it sets, which are likely to differ depending on the political philosophy behind the framework. There are few laws (e.g., building codes) requiring homeowners to take precautionary measures. However, during recent years in Germany, private responsibility for flood damage reduction has been increasingly emphasised and embedded into flood risk management (Environment Agency 2010). According to § 5 of the German Federal Water Resource Act that was enacted in 2009, every person that could be affected by a flood is obliged to undertake appropriate actions that are reasonable and within one's means to reduce flood impacts and damage (Wasserhaushaltsgesetz 2009).

Previous studies have shown that personal flood experience is a strong trigger for flood precautionary behaviour (Grothmann and Reusswig 2006; Siegrist and Gutscher 2006, 2008; Kreibich and Thieken 2009; Kreibich et al. 2009b, 2011a; Bubeck et al. 2012a). For instance, it has been shown by Smith (1981) and Wind et al. (1999) that damage is reduced significantly if people have had frequent and recent experience of flooding. Bubeck et al. (2012b) provides an overview on the long-term development of four different types of precautionary measures amongst flood-prone households between 1980 and 2011 along the River Rhine in Germany. This long-term development also shows a clear relationship between the occurrence of food events and the implementation of precautionary measures by private households. For instance, the number of implemented measures sharply increased after the severe flood event in 1993. That flood experience strongly influences the adoption of precautionary measures is also confirmed by strong correlations between the number of reported flood events per year and the number of implemented measures (Bubeck et al. 2012b). From an economic point of view, it is important that such measures are efficient and show a benefit–cost ratio larger than one (Kreibich et al. 2011b, 2012). Additionally, financial incentives can help individuals and companies to invest in self-protection. Such incentives can be provided either through appropriate insurance contracts (Kleindorfer and Kunreuther 1999; Botzen et al. 2009; Holub and Fuchs 2009; Seifert et al. 2013) or else through governmental schemes or aid supporting private precautionary measures.

In line with the growing importance of private flood-damage-reducing measures in risk-based flood management concepts, there has been also a renewed interest in the factors that motivate households to undertake such measures. Initially, the literature focussed on flood risk perceptions (Grothmann and Reusswig 2006), and it was commonly argued that people undertake precautionary measures to reduce a risk they perceive as being high (e.g. Plapp and Werner 2006). A review of risk perception and other factors that influence flood mitigation behaviour is provided by Bubeck et al. (2012a). It shows that empirical studies that have investigated the relation between flood risk perceptions and the adoption of private flood-damage-reducing measures reveal only a weak or no statistically significant relation (e.g. Kreibich et al. 2005a; Siegrist and Gutscher 2006; Takao et al. 2004; Thieken et al. 2006; Miceli et al. 2008). Several articles have addressed and discussed the reasons for this weak relationship between risk perceptions and mitigation behaviour in recent years and explanations range from methodological aspects associated with cross-sectional studies to the psychological process of decision making under risk (Bradford et al. 2012; Wachinger et al. 2013; Siegrist 2013; Bubeck et al. 2012a, 2013). Moreover, a number of studies increasingly focussed on other factors that could possibly drive mitigation behaviour and several studies applied variables of psychological concepts to explain decision making in response to threats, such as Protection Motivation Theory (PMT) (Grothmann and Reusswig 2006; Bubeck et al. 2013; Koerth et al. 2013; Poussin et al. 2014). For instance, the investigation of survey data of 752 flood-prone households along the river Rhine confirms that flood-coping appraisal, which is one component of PMT, is an important factor of influence on precautionary behaviour (Bubeck et al. 2013). Coping appraisal is comprised of three elements and refers to a respondent's self-evaluation of his or her ability to implement a certain measure (self-efficacy), the belief that the respective measure is effective in preventing or reducing damage (response efficacy) and the expected costs of that measure (Rogers 1975, 1983; Maddux and Rogers 1983). This study reveals that both self-efficacy and response efficacy considerably influence flood mitigation behaviour, whereas response costs associated with implementing precautionary measures are mostly insignificant; with the exception of financial costs of implementing building precautionary measures, probably due to the high costs associated with this type of measure. Reynaud et al. (2013) revealed that threat appraisal, reliance on non-individual flood protection and, to a much lesser extent, threat experience appraisal processes are significant determinants of flood protective behaviours of Vietnamese households. However, results also show that whilst private flood-damage-reducing measures were found to be appraised positively, they are often postponed (Bubeck et al. 2013).

4.2 Damage-reducing effects

Not many studies investigate the quantitative damage-reducing effect of private precautionary measures, probably also due to a lack of data. However, there is some evidence that these measures are effective in reducing damage and are also often efficient (ICPR 2002; Kreibich et al. 2005a, 2011b, 2012; Olfert and Schanze 2008; Holub and Fuchs 2008). Some studies aim to quantify the damage-reducing effect of different measures at the building level (Table 1). These include scientific studies based on empirical damage data (e.g. Kreibich et al. 2005a; Bubeck et al. 2013; Hudson et al. 2014) as well as practical studies based on expert judgment and/or a rather intransparent database (e.g. ICPR 2002; ABI 2003; DEFRA 2008). Table 1 shows that the spread of revealed damage reduction due to specific measures is large, which is quite clear, since the effectiveness depends on the specific local conditions during a flood. For instance, the effectiveness of a sealed cellar is significantly reduced if the cellar must be flooded to counteract buoyancy forces (ICPR 2002). The comparison between the more general studies (DEFRA 2008; ICPR 2002) and the empirical study related to an extreme event suggests that the effectiveness of dry flood proofing is strongly reduced during an extreme event, which is not so much the case for wet flood proofing (Table 1). Comparing the effect of dry-proofing measures, which rely on a sufficient early warning lead time to be installed, i.e. temporary resistance like mobile water barriers on the one hand and on the other hand, permanent measures like flood adapted building structure reveal no large difference (Table 1). This might be due to the fact, that the studies were undertaken in large river catchments like the Elbe (Kreibich et al. 2005a) or the Rhine (ICPR 2002) where lead times of many hours to days are common. However, the situation might be very different in headwater catchment in mountainous areas where warning times might be too short to install temporary measures in time.

It is difficult to make generalisations about the damage-reducing effects of emergency measures (e.g. securing furniture or equipment), since they depend strongly on the effectiveness of early warning and response as well as on the intensity of the flood event. Only very few studies investigated their effects: ICPR (2002) estimated that the total damage to residential contents may be reduced by 20–50 % due to removing furniture and equipment or to elevating it. A reduction of damage potential by 50–75 % may be possible due to emergency measures in industry and trade (ICPR 2002). Kreibich et al. (2007) estimated an average damage reduction of 52 % concerning goods, products or stock and of 28 % concerning equipment given companies had been able to undertake emergency measures successfully during the extreme flood in 2002.

Further examples of scientific empirical studies are the following: Bubeck et al. (2012b) followed a repeated-measure design to compare the amount of flood damage suffered by the same households during two consecutive flood events along the German part of the Rhine in 1993 and 1995, including only these households that reported identical water levels during both flood events. The trend of lower flood damage in 1995 was attributed to a considerable increase in the implementation of private precautionary measures after 1993. Hudson et al. (2014) applied an econometric evaluation technique called Propensity Score Matching to a survey of German households

Table 1 Damage-reducing effects of precautionary measures undertaken by private households on the building level

Measure	Reduction	Source
Wet proofing		
Flood-adapted use	46–48 %, 30–40 %	Kreibich et al. 2005a; ICPR 2002
Flood-adapted interior fitting	53 %, 15–35 %, 35–45 %	Kreibich et al. 2005a; ICPR 2002; DEFRA 2008
Installation of heating and electrical utilities in higher storeys	36 %	Kreibich et al. 2005a
Avoidance of contamination	35–52 %, >50 %	Kreibich et al. 2005a; ICPR 2002
Dry proofing		
Temporary resistance, e.g. mobile water barriers	29 %, 60–80 %, 50 %	Kreibich et al. 2005a; ICPR 2002; DEFRA 2008
Flood-adapted building structure, e.g. cellar sealing, permanent flood proof doors and windows	24 %, 10–85 %, 65–84 %	Kreibich et al. 2005a; ICPR 2002; DEFRA 2008
Building without cellar	22–24 %	Kreibich et al. 2005a

along three major rivers that were flooded in 2002, 2005 or 2006. This approach aimed at avoiding a biased estimate, which can occur if risk characteristics differ between individuals who have, or have not, implemented precautionary measures. Bias-corrected effectiveness estimates of several precautionary measures show that these measures are very effective since they prevent between €6700–14,000 of flood damage. The empirical study by Kreibich et al. (2005b) showed that various building precautionary measures were also able to reduce mean (median) building damage of companies in Germany. However, differences were not significant, most likely due to the heterogeneity of the companies (Kreibich et al. 2005b).

Furthermore, there are modelling studies that aim to estimate the damage- or risk-reducing effect of such measures at a regional scale (e.g. Bubeck and De Moel 2010; Poussin et al. 2012; De Moel et al. 2014). These studies have used expert judgment and insights gained from empirical studies (like the ones listed in Table 1) as input. Poussin et al. (2012) looked at the Meuse valley in the south of The Netherlands and found 10–15 % risk reduction via wet proofing and 15–25 % reduction via dry proofing. Also in New York City, a considerable potential for damage reduction has been shown (Aerts et al. 2013): Depending on the height up to which the measures are taken, the risk of buildings could be reduced by 10–30 % for wet proofing and 20–50 % for dry proofing. Note that this relates only to the risk of buildings, whereas the study of Poussin et al. (2012) looked at reductions on the overall risk. A high potential for damage-reducing measures has also been found for flooding in the (usually elevated) unembanked area of the Rotterdam region (De Moel et al. 2014). Here, reductions in total risk of ~30 % for wet proofing, and ~60 % for dry proofing were found. This can be explained by the relative low inundation depths there (generally<1 m), resulting from the systematic elevation of the unembanked area to accommodate developments. This becomes even more apparent when only the flood risk to buildings is considered, which is almost completely nullified when all buildings are elevated for 1 m (De Moel et al. 2014).

Costs associated with implementing building precautionary measures have been extensively documented in the US, but less in other countries (Table 2). For instance, Aerts et al. (2013) estimated combined costs for different types of buildings for New York based on detailed costs of many different activities (FEMA 2009; Jones et al. 2006). However, some studies also estimated aggregate costs for different types of houses for The Netherlands, Germany and the UK (Table 2). The estimates from the US illustrate that elevating an existing building is very costly (€24,000–27,000), however, when implemented at the time of building, the extra costs are quite low (Aerts et al. 2013).

Whilst important, the technical cost of the measure itself is not the only consideration associated with precautionary measures. Often, such a measure involves certain adjustments to a building structure, which are outside the normal building standards. This may be associated with substantial administrative paperwork, which has its cost as well. For instance, just surveying a property for advice on maintenance and repairs that may improve the water resistance is estimated to cost £300 (€383) by ABI (2003). Moreover, the implementation costs can be borne by various actors. This could be the project developer, who will most likely include it in the selling price; for instance, in the case of sustainable homes in the US. Costs can also be borne by a local authority (municipality, water board) who wants certain buildings to be adapted, or of course by the owners of a home themselves.

Implementing a precautionary measure is economically beneficial, if the aggregated benefits (damage reduction) outweigh the costs (investment and maintenance costs) over the calculation period or lifetime of the measure. Few cost–benefit analyses have been undertaken: For example, Holub and Fuchs (2008) investigate the cost-effectiveness of precautionary measures on a regional basis as follows: First, they estimate the natural hazard risk posed in

Table 2 Examples of cost estimates of damage-reducing measures at the building level

Measure	Measure	Cost per house	Country	Source
Elevating	Elevating 60–180 cm	€24,000 ($33,000)–€27,000 ($37,000)	USA	Aerts et al. 2013[a]
	Elevating new 60–180 cm	€1800 ($2500)–€5500 ($7500)	USA	Aerts et al. 2013
	Elevate column 50–100 cm	€1200–1900	NL	Gersonius et al. 2008
	Elevate wall 30–90 cm	€2000–4300	NL	Gersonius et al. 2008
Wet proofing	Wet proofing 60–180 cm	€1600 ($2150)–€6200 ($8500)	USA	Aerts et al. 2013
	Wet proofing 100 cm	€17,700	NL	Gersonius et al. 2008
	Flood-proofed oil tank	€1009	GER	Kreibich et al. 2011b, 2012
	Move kitchen to first floor	€7018 (£5500)–€7656 (£6000)	UK	ABI 2003
	Resilient kitchen (raised appliances, resilient units)	€3828 (£3000)	UK	DEFRA 2007
Dry proofing	Dry proofing 60–180 cm	€6100 ($8300)–€9200 ($12,600)	USA	Aerts et al. 2013
	Dry proofing temp. 90 cm	€2300	NL	Gersonius et al. 2008
	Dry proofing perm. 90 cm	€7600	NL	Gersonius et al. 2008
	Waterproof cellar using Bitumen sealing	€18,532	GER	Kreibich et al. 2011b, 2012
	Waterproof cellar using waterproof concrete	€21,148	GER	Kreibich et al. 2011b, 2012
	Mobile water barrier	€6100	GER	Kreibich et al. 2011b, 2012
	Raise floor levels	€31,900 (£25,000)–€57,037 (£44,700)	UK	ABI 2003
	Install one-way valves	€1914 (£1500)	UK	ABI 2003
	Temporary resistance, e.g., flood guards	€2552 (£2000)–€5104 (£4000)	UK	DEFRA 2007
	Basement or cellar tanking	€7656 (£6000)–€12,760 (£10,000)	UK	DEFRA 2007

[a] Note that the estimates of Aerts et al. (2013) are mainly based on FEMA (2009) and Jones et al. (2006)

their sample area. Once the level of risk is known, the sample area is divided into different risk zones and the level of exposure within a risk band is used to estimate damage. Holub and Fuchs (2008) then proceed to calculate the benefits of the measures by assuming that a precautionary measure prevents all damage up to a certain severity of hazard. Kreibich et al. (2011b, 2012) follow a micro-economic approach on household level, which reveals that mainly small investments like the installation of an oil tank protection can prevent high damage at very low cost and are as such particularly efficient. DEFRA (2008) found that measures designed to keep water out of the individual properties are economically worthwhile for properties with an annual chance of flooding of 2 % or above (50-year return period).

4.3 Non-structural measures to adapt to changes in risk

Only few studies so far investigated to what extent non-structural measures are a promising adaptation strategy to offset projected increases in flood risk (i.e. probability times damage) in many areas caused by climate change and increasing vulnerability including exposure (e.g. Dawson et al. 2014; De Moel et al. 2014; Aerts et al. 2014). Dawson et al. (2014) examine the risk-reducing effect of spatial planning policies, insurance and flood resilient construction on expected annual damage (EAD) in the Thames Estuary over extended time scales, considering socio-economic and climate change. The study estimates a substantial risk-reduction potential when a portfolio of these measures is applied. Moreover, the study also shows that earlier action further increases the benefits that can be achieved with these measures. De Moel et al. (2014) also examine current and future flood risk for an unembanked area in Rotterdam, The Netherlands, and evaluate the risk-reducing effect of three non-structural measures: wet proofing, dry proofing and elevating buildings. This study finds that the deployment of these measures could completely offset the projected increase in flood risk caused by climate change, which is expected to double by 2100 if no adaptation measures are undertaken. Poussin et al. (2012) estimate future flood risk for the Meuse basin and report a risk-reduction capacity of 21–40 % for non-structural measures at the building level. In combination with spatial planning policies, a reduction of up to 60 % can be achieved. Aerts et al. (2014) employ a probabilistic flood risk model in combination with a benefit–cost analysis to evaluate different flood risk management strategies for New York. The risk assessment combines a probabilistic storm surge model with information on exposed buildings and vehicles at the census level as well as indirect costs. Risk is calculated for the current situation, 2040 and 2080, taking the effects of climate change and urban development into account. The study concludes that non-structural measures such as building elevation and the protection of critical infrastructure are the most cost-efficient strategies to address future flood risk in New York. An Austrian case study at the river Lech focussing at the near future until 2030 demonstrated that adaptation by non-structural measures such as stricter land-use regulations or enhancement of private precaution may be capable of reducing flood risk by around 30 % (Thieken et al. 2014). An assessment of the effectiveness of flood adaptation strategies until 2100 for Ho Chi Minh City, Vietnam, revealed best benefit–cost ratios for the adaptation strategies wet and dry proofing (Lasage et al. 2014). Based on expert judgment, an individual residential building damage reduction of 20 % due to wet proofing (below 2–3 m of inundation depth) and of 85–100 % due to dry proofing (below 1–1.5-m inundation depth) was assumed (Lasage et al. 2014). In conclusion, all of the studies confirm that non-structural measures can play an important role to tackle projected increases in flood risk due to global change.

5 Conclusions

Empirical studies and model results suggest a high potential for adaptation strategies of integrated risk management approaches including spatial planning and private precautionary measures. Damage-reducing measures are expected to gain even more importance given the increase in flood risk due to climate change and increasing vulnerability. There are several reasons why damage-reducing measures should complement defensive measures for the development of an effective adaption strategy. Zoning policies and flood proofing of buildings is particularly relevant for new developments, where the location can still be adjusted and additional costs for building precautionary measures are relatively small. Optimising future developments (or re-developments) in a risk neutral way avoids the levee effect. Moreover, from a flexibility or robustness point of view (De Bruijn 2005; Mens et al. 2011), relying only on structural measures may not be desirable since adaptive management is hardly possible and potential future disasters may become unmanageable. For instance, in Belgium, the option of a surge barrier to protect the Scheldt estuary was not chosen because, amongst various reasons, it cannot provide absolute protection and consequences would be devastating when it would fail (Sigmaplan 2014). Precautionary measures, on the other hand, also reduce consequences in case of a defence failure and an inundation occurring, thus contributing to system robustness. In the face of uncertainty about future extreme events due to global change, such private damage-reducing measures are thus a valuable contribution to a flexible, robust adaptation and flood risk management strategy.

Despite their potential for adaptation at the local, regional and national scale and the fact that flood zoning and land-use planning are part of flood risk management in many countries, their actual contribution to risk mitigation is often low. Similarly, private flood damage reduction has become an integral component of contemporary flood risk management, but many flood endangered households and companies still do not undertake any precautionary measures, despite the fact that these effectively reduce damage and are efficient in many situations. Various reasons have been discussed for the often low implementation levels. For instance, it is usually difficult for home or company owners to estimate the efficiency of such up-front investments, due to uncertainties associated with the damage-reducing effects of these measures as well as with the flood probabilities (Kunreuther et al. 2007). This trade-off between short-term investments and long-term benefits is likely to be even harder for poor people in developing countries. Another reason relates to locked-in situations. In places with high protection standards (e.g. 1/1000 years in The Netherlands), one will very rarely benefit from damage-reducing measures. Consequently, these measures do not score well in cost–benefit analysis, whilst often upgrading the protection standard does. Furthermore, behavioural aspects have been discussed such as wishful thinking and denial of flood risk or postponement of measures that are generally considered useful by private households (Bubeck et al. 2013). In spatial planning (which is often conducted on the local level), often short-term interests dominate, such as housing availability and the creation of jobs in new industrial areas, instead of the longer term flood risk management interest (Wilson 2006). Some argue that financial compensation should be given, for instance, to those communities that cannot grow due to flood risk (Böhm et al. 2004; Hooijer et al. 2004).

Based on this review of the potential of flood-damage-reducing measures as components of adaptation strategies at local, regional and national scales, more research on the exact mechanisms how flood zoning, land-use planning and private precautionary measures are implemented in different countries with their varying governance contexts should be undertaken to support cross-country learning. More research needs to be undertaken in developing countries where high increases in flood risk are expected due to climate change and fast grow rates of populations and economies and where regulations may be less enforced. However, most importantly, further efforts are required to increase the implementation levels of damage-reducing measures, via better cooperation between all stakeholders, improved risk communication, (financial) incentives or stricter legal regulations in the framework of national adaptation strategies.

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References

ABI (2003) Assessment of the cost and effect on future claims of installing flood damage resistant measures. Association of British Insurers (ABI), London
Aerts JCJH, Botzen WJW (2011) Flood-resilient waterfront development in New York City: bridging flood insurance, building codes, and flood zoning. Ann N Y Acad Sci 1227(1):1–82
Aerts JCJH, Botzen WJW, De Moel H et al (2013) Cost estimates for flood resilience and protection strategies in New York city. Ann N Y Acad Sci 1294:1–104
Aerts JCJH, Botzen WJW, Emanuel K et al (2014) Evaluating flood resilience strategies for coastal mega-cities. Science 344:473–475. doi:10.1126/science.1248222
Alexander ER (2002) The public interest in planning: from legitimation to substantive plan evaluation. Planning Theory 1(3):226–249
Arciniegas G, Jansen R, Rietveld P (2013) Effectiveness of collaborative map-based decision support tools: results of an experiment. Environ Model Software 39:159–175
Ball T, Werritty A, Geddes A (2013) Insurance and sustainability in flood-risk management: the UK in a transitional state. Area 45(3):266–272
Barredo JI (2009) Normalised flood losses in Europe: 1970–2006. Nat Hazards Earth Syst Sci 9:97–104. doi:10.5194/nhess-9-97-2009
Becker A, Grünewald U (2003) Flood risk in central Europe. Science 300:1099
Beckers JVL, De Bruijn KM (2011) Analyse van Slachtofferrisico's, Waterveiligheid 21e eeuw, Report 1204144-005, Deltares, Delft
Benoît R, Forget S, Rouselle J (2003) The effectiveness of flood damage reduction measures in the Montreal region. Nat Hazards 28:367–385
Berkes F, Colding J, Folke C (eds) (2003) Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge
Böhm HR, Haupter B, Heiland P et al (2004) Implementation of flood risk management measures into spatial plans and policies. River Res Appl 20:255–267
Botzen WJW, Aerts JCJH, van den Bergh JCJM (2009) Dependence of flood risk perceptions on socioeconomic and objective risk factors. Water Resour Res 45:W10440. doi:10.1029/2009WR007743
Bradford RA, O'Sullivan JJ, van der Craats IM et al (2012) Risk perception-issues for flood management in Europe. Nat Hazards Earth Syst Sci 12(7):2299–2309
Bubeck P, De Moel H (2010) Sensitivity analysis of flood damage calculations for the river Rhine. 32 Report IVM, DG Waters, The Netherlands
Bubeck P, Botzen WJW, Aerts JCJH (2012a) A review of risk perceptions and other factors that influence flood mitigation behavior. Risk Anal 32(9):1481–1495
Bubeck P, Botzen WJW, Kreibich H et al (2012b) Long-term development and effectiveness of private flood mitigation measures: an analysis for the German part of the river Rhine. Nat Hazards Earth Syst Sci 12(11): 3507–3518
Bubeck P, Botzen WJW, Kreibich H et al (2013) Detailed insights into the influence of flood-coping appraisals on mitigation behaviour. Glob Environ Chang 23(5):1327–1338
Bubeck P, Kreibich H, Penning-Rowsell E, Botzen WJW, De Moel H, Klijn F (2014) Explaining differences in flood management approaches in Europe and the USA—a comparative analysis. Journal of Flood Risk Management (in press)
Burby RJ (2001) Flood insurance and floodplain management: the US experience. Environ Hazards 3:111–122

Burby RJ, Beatley T, Berke PR et al (1999) Unleashing the power of planning to create disaster-resistant communities. J Am Plann Assoc 65(3):247–258. doi:10.1080/01944369908976055
Burby RJ, Salvesen D, Creed M (2006) Encouraging residential rehabilitation with building codes: New Jersey's experience. J Am Plann Assoc 72(2):183–196. doi:10.1080/01944360608976738
BWG (Swiss Federal Office for Water and Geology) (ed) (2001) Hochwasserschutz an Fliessgewässern. BWG, Bern
Cabinet Office (2008) The Pitt Review—learning lessons from the 2007 floods, Cabinet Office, 22 22 Whitehall, London SW1A 2WH. http://webarchive.nationalarchives.gov.uk/20100807034701/http:/archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html. Accessed 17 Dec 2014
Chatterjee M (2010) Slum dwellers response to flooding events in the megacities of India. Mitig Adapt Strateg Glob Chang 15:337–353
Cho R (2011) Making room for rivers: a different approach to flood control. Water matters—news from the Columbia Water Center. http://blogs.ei.columbia.edu/2011/06/07/making-room-for-rivers-a-different-approach-to-flood-control/
Cohen GA (2000) If you're an egalitarian, how come you're so rich. Harvard Univ Pr, Harvard
Dawson RJ, Ball T, Werritty J et al (2014) Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmenmtal change. Glob Environ Chang 21(2):628–646
De Bruijn KM (2005) Resilience and flood risk management: a systems approach applied to lowland rivers. Delft University Press, Delft
De Bruijn KM, Klijn F (2009) Risky places in The Netherlands: a first approximation for floods. J Flood Risk Manag 2:58–67
De Moel H, van Alphen J, Aerts JCJH (2009) Flood maps in Europe—methods, availability and use. Nat Hazards Earth Syst Sci 9(2):289–301
De Moel H, Aerts JCJH, Koomen E (2011) Development of flood exposure in The Netherlands during the 20th and 21st century. Glob Environ Chang 21(2):620–627. doi:10.1016/j.gloenvcha.2010.12.005
De Moel H, van Vliet M, Aerts JCJH (2014) Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, The Netherlands. Reg Environ Chang 14:895–908
DECC-NSW (Department of Environment and Climate Change New South Wales) (2008) Reducing vulnerability of buildings to flood damage—guidance on building in flood prone areas. Prepared for the Hawkesbury-Nepean Floodplain Management Steering Committee. DECC-NSW, Australia
DEFRA (Department for Environment, Food and Rural Affairs) (2005) Making space for water—taking forward a new government strategy for flood and coastal erosion risk management in England. First government response to the autumn 2004 'making space for water' consultation exercise. HM Treasury, Office of the Deputy Prime Minister, Department for Transport and DEFRA
DEFRA (Department for Environment, Food and Rural Affairs) (2007) Flood resistance and resilience solutions: an R&D scoping study. R&D Technical Report, DEFRA, http://archive.defra.gov.uk/environment/flooding/documents/manage/frrs-scope.pdf. Cited 7 Nov 2014
DEFRA (Department for Environment, Food and Rural Affairs) (2008) Developing the evidence base for flood resistance and resilience: Summary Report. R&D Technical Report FD2607/TR1. Environment Agency and DEFRA, London
Di Baldassarre G, Castellarin A, Brath A (2009) Analysis of the effects of levee heightening on flood propagation: example of the River Po, Italy. Hydrol Sci J 54(6):1007–1017
Egli T (2000) Gefahrenkarten für die Bauvorsorge und Notfallplanung. Workshop Vorbeugender Hochwasserschutz auf kommunaler Ebene 13./14.12.2000. Dresden Institut für ökologische Raumentwicklung. Umweltbundesamt, Berlin
Eikelboom T, Janssen R (2013) Interactive spatial tools for the design of regional adaptation strategies. J Environ Manage 127:6–14
FEMA (1998a) Homeowner's guide to retrofitting—six ways to protect your house from flooding. FEMA Publications, Federal Emergency Management Agency, Washington, DC
FEMA (1998b) Repairing your flooded home. FEMA Publications, Federal Emergency Management Agency, Washington, DC
FEMA (1999) Protecting building utilities from flood damage—principles and practices for the design and construction of flood resistant building utility systems. FEMA Publications, Federal Emergency Management Agency, Washington, DC
FEMA (2009) Homeowner's guide to retrofitting, 2nd edn. FEMA Publications, Federal Emergency Management Agency, Washington, DC. http://www.fema.gov/library/viewRecord.do?id=1420
Environment Agency (2003a) Damage limitation—how to make your home flood resistant. Environment Agency, Bristol
Environment Agency (2003b) Flood products. Using flood protection products—a guide for homeowners. Environment Agency, Bristol

Environment Agency (2010) Flood and coastal risk management risk mapping strategy 2010–2015. Environment Agency, Bristol
SEPA (2003) Flood alleviation products. Scottish Environment Protection Agency, Stirling
Erdlenbruch K, Thoyer S, Grelot F et al (2009) Risk-sharing policies in the context of the French flood prevention action programmes. J Environ Manage 91(2):363–369. doi:10.1016/j.jenvman.2009.09.002
European Commission (2000) Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the community action in the field of water policy. Off J L 327
European Commission (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. Off J EU 6, L 288/27–34
Evans E, Ashley R, Hall J, Penning-Rowsell EP, Sayers PB, Thorne CR et al (2004) Foresight future flooding, scientific summary: Volume 2: managing future risks. Office of Science and Technology, London
Federal Environment Agency (2010) Water resource management in Germany. Part 1: Fundamentals. Umweltbundesamt, Dessau-Roßlau
Fleischhauer M (2005) Country report—France. In: Greiving S, Fleischhauer M, Wanczura S (eds) Report on the European scenario of technological and scientific standards reached in spatial planning versus natural risk management. ARMONIA Project, Dortmund
APFM (2007) The role of land-use planning in flood management—a tool for integrated flood management. Associated Programme on Flood Management (APFM) Technical Document No. 12, Flood management tools series. World Meteorological Organisation, Global Water Partnership
MUF (1998) Hochwasserhandbuch—Leben, Wohnen und Bauen in hochwassergefährdeten Gebieten des Ministeriums für Umwelt und Forsten Rheinland-Pfalz. Ministerium für Umwelt und Forsten Rheinland-Pfalz (MUF), Mainz
Fraser Basin Council and Arlington Group (2008) Flood hazard area land use management. Review of flood hazard area land use management in B.C. Fraser Basin Council and Arlington Group, Vancouver, BC
Fuchs S, Spachinger K, Dorner W et al (2009) Evaluating cartographic design in flood risk mapping. Environ Hazards 8(1):52–70
Gersonius B, Zevenbergen C, Puyan N, Billah MMM (2008) Efficiency of private flood proofing of new buildings—adapted redevelopment of a floodplain in the Netherlands. WIT Transactions on Ecology and the Environment, Vol 118: Flood Recovery, Innovation and Response. DOI 10.2495/FRIAR080241
Glavovic BC (2010) The role of land-use planning in disaster risk reduction: an introduction to perspectives from Australia. The Australian Journal of Disaster and Trauma Studies 1 http://trauma.massey.ac.nz/issues/2010-1/editorial.htm
Graham M, Ogilvie J, Reid T et al (2012) Best practices for managing surface water flooding: applying lessons learned in the UK to Canada. Proc Annu Conf Can Soc Civ Eng 2:1053–1062
Green CH, Parker DJ, Tunstall SM (2000) Assessment of flood control and management options. WCD Thematic Review Options Assessment: IV.4. Prepared for the World Commission on Dams (WCD). Flood Hazard Research Centre, Middlesex University, London
Grothmann T, Reusswig F (2006) People at risk of flooding: why some residents take precautionary action while others do not. Nat Hazards 38(1–2):101–120
Hampshire Flood Steering Group (2002) Managing flood risks in parishes—a best practice guide, 2nd edn. Environment Agency, Bristol
Heiland P (2002) Vorsorgender Hochwasserschutz durch Raumplanung, interregionale Kooperation und ökonomischen Lastenausgleich. Schriftenreihe WAR 143, Technische Universität Darmstadt, Darmstadt
Holub M, Fuchs S (2008) Benefits of local structural protection to mitigate torrent-related hazards. In: Brebbia CA, Beritatos E (eds) Risk analysis VI. WIT Transactions on Information and Communication Technologies, WIT Press, Vol. 39, pp 401–411
Holub M, Fuchs S (2009) Mitigating mountain hazards in Austria—legislation, risk transfer, and awareness building. Nat Hazards Earth Syst Sci 9:523–537. doi:10.5194/nhess-9-523-2009
Holub M, Hübl J (2008) Local protection against mountain hazards—state of the art and future needs. Nat Hazards Earth Syst Sci 8:81–99. doi:10.5194/nhess-8-81-2008
Holway JM, Burby RJ (1993) Reducing flood losses local planning and land use controls. J Am Plann Assoc 59(2):205–216. doi:10.1080/01944369308975586
Hooijer A, Klijn F, Pedroli GBM et al (2004) Towards sustainable flood risk management in the Rhine and Meuse river basins: synopsis of the findings of IRMA-SPONGE. River Res Appl 20:343–357
Hudson P, Botzen WJW, Kreibich H et al (2014) Evaluating the effectiveness of flood damage mitigation measures by the application of propensity score matching. Nat Hazards Earth Syst Sci 14(7):1731–1747
ICPR (International Commission for the Protection of the Rhine) (2002) Non-structural flood plain management: measures and their effectiveness. ICPR, Koblenz

Jones CP, Coulbourne WL, Marshall J, Rogers SM Jr, Jones C, et al. (2006) Evaluation of the National Flood Insurance Program's building standards. American Institutes for Research and the NFIP Evaluation Working Group. http://www.fema.gov/library/viewRecord.do?id=2592
DKKV (2003) Hochwasservorsorge in Deutschland—Lernen aus der Katastrophe 2002 im Elbegebiet. Schriftenreihe des DKKV 29, Lessons Learned. Deutsches Komitee für Katastrophenvorsorge (DKKV), Bonn
Keessen AM, Hamer JM, Van Rijswick HFMW, Wiering M (2013) The concept of resilience from a normative perspective: examples from Dutch adaptation strategies. 18(2)
Kinzig AP (2001) Bridging disciplinary divides to address environmental and intellectual challenges. Ecosystems 4:709–715
Kleindorfer PR, Kunreuther H (1999) The complementary roles of mitigation and insurance in managing catastrophic risks. Risk Anal 19(4):727–738
Klijn F, Asselman NEM, Van der Most H (2010) Compartmentalisation: flood consequences reduction by splitting up large polder areas. J Flood Risk Manage 3:3–17. doi:10.1111/j.1753-318X.2009.01047.x
Koerth J, Jones N, Vafeidis AT et al (2013) Household adaptation and intention to adapt to coastal flooding in the Axios–Loudias–Aliakmonas National Park, Greece. Ocean Coast Manag 82:43–50
Koks EE, De Moel H, Aerts JCJH et al (2014) Effect of spatial adaptation measures on flood risk: study of coastal floods in Belgium. Reg Environ Chang 14(1):413–425
Kreibich H, Thieken AH (2009) Coping with floods in the city of Dresden, Germany. Nat Hazards 51(3):423–436
Kreibich H, Thieken AH, Petrow T et al (2005a) Flood loss reduction of private households due to building precautionary measures: lessons learned from the Elbe flood in august 2002. Nat Hazards Earth Syst Sci 5(1):117–126
Kreibich H, Thieken AH, Müller M, Merz B (2005b) Precautionary measures reduce flood losses of households and companies—insights from the 2002 flood in Saxony, Germany. In: van Alphen J, Beek E, Taal M (eds) Floods, from defence to management. Taylor and Francis, Philadelphia, pp 851–859
Kreibich H, Müller M, Thieken AH et al (2007) Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany. Water Resour Res 43:W03408. doi:10.1029/2005WR004691
Kreibich H, Piroth K, Seifert I et al (2009a) Is flow velocity a significant parameter in flood damage modelling? Nat Hazards Earth Syst Sci 9:1679–1692
Kreibich H, Thieken AH, Grunenberg H et al (2009b) Extent, perception and mitigation of damage due to high groundwater levels in the city of Dresden, Germany. Nat Hazards Earth Syst Sci 9(4):1247–1258
Kreibich H, Seifert I, Thieken AH et al (2011a) Recent changes in flood preparedness of private households and businesses in Germany. Reg Environ Chang 11(1):59–71
Kreibich H, Christenberger S, Schwarze R (2011b) Economic motivation of households to undertake private precautionary measures against floods. Nat Hazards Earth Syst Sci 11(2):309–321
Kreibich H, Christenberger S, Schwarze R (2012) Corrigendum to "Economic motivation of households to undertake private precautionary measures against floods" published in Nat hazards earth Syst Sci 11:309–321, 2011. Nat Hazards Earth Syst Sci 12:391–392
Kreibich H, van den Bergh JCJM, Bouwer LM et al (2014a) Costing natural hazards. Nat Clim Chang 4:303–306
Kreibich H, Bubeck P, Kunz M et al (2014b) A review of multiple natural hazards and risks in Germany. Nat Hazards 74(3):2279–2304
Kummu M, De Moel H, Ward PJ et al (2011) How close do we live to water? A global analysis of population distance to freshwater bodies. PLoS One 6(6):e20578
Kundzewicz ZW, Ulbrich U, Brücher T et al (2005) Summer floods in Central Europe—climate change track? Nat Hazards 36:165–189
Kundzewicz ZW, Kanae S, Seneviratne SI et al (2013) Flood risk and climate change: global and regional perspectives. Hydrol Sci J 59(1):1–28. doi:10.1080/02626667.2013.857411
Kunreuther H, Meyer RJ, Michel-Kerjan E (2007) Strategies for better protection against catastrophic risks. Working Paper 2007-09-14. Risk Management and Decision Processes Center, The Wharton School of the University of Pennsylvania
Lane SN, Landström C, Whatmore SJ (2011) Imagining flood futures: risk assessment and management in practice. Phil Trans R Soc A 369:1784–1806
Lasage R, Veldkamp TIE, De Moel H et al (2014) Assessment of the effectiveness of flood adaptation strategies for HCMC. Nat Hazards Earth Syst Sci 14(6):1441–1457
Li Y-S, Raso G, Zhao Z-Y et al (2007) Large water management projects and schistosomiasis control, Dongting lake region, China. Emerg Infect Dis 13(7):973–979
Lumbroso D, Vinet F (2011) A comparison of the causes, effects and aftermaths of the coastal flooding of England in 1953 and France in 2010. Nat Hazards Earth Syst Sci 11(8):2321–2333

Maddux JE, Rogers RW (1983) Protection motivation and selfefficacy. A revised theory of fear appeals and attitude-change. J Exp Soc Psychol 19(5):469–479
Marco JB (1994) Flood risk mapping. In: Rossi G, Harmancioglu N, Yevjevich V (eds) Coping with floods. Kluwer Academic Publishers, Dordrecht, pp 353–373
Menendez M (2000) Design discharge calculations and flood plain management. European Commission (Directorate General XII): FLOODaware Final report, Cemagref, 53–82
Mens MJP, Klijn F, De Bruijn KM et al (2011) The meaning of system robustness for flood risk management. Environ Sci Pol 14:1121–1131. doi:10.1016/j.envsci.2011.08.003
Merz B, Thieken AH, Gocht M (2007) Flood risk mapping at the local scale: concepts and challenges. In: Begum S, Stive MJF, Hall JW (eds) Flood risk management in Europe—innovation in policy and practice. Springer, Dordrecht, pp 231–251
Merz B, Kreibich H, Schwarze R et al (2010) Assessment of economic flood damage. Nat Hazards Earth Syst Sci 10:1697–1724. doi:10.5194/nhess-10-1697-2010
Merz B, Kundzewicz ZW, Delgado J, Hundecha Y, Kreibich H (2012) Detection and attribution of changes in flood hazard and risk. In: Kundzewicz ZW (ed) Changes in flood risk in Europe. IAHS Special Publication 10:435–458
Meyer V, Kuhlicke C, Luther J et al (2012) Recommendations for the user-specific enhancement of flood maps. Nat Hazards Earth Syst Sci 12:1707–1716
Miceli R, Sotgiu I, Settanni M (2008) Disaster preparedness and perception of flood risk: a study in an alpine valley in Italy. J Environ Psychol 28(2):164–173
Ministry of Infrastructure and the Environment (2011) Besluit algemene regels ruimtelijke ordening
Ministry of Transport and Water, Ministry of Housing Spatial Planning and Environment and Ministry of Agriculture Nature and Food quality (2009) Beleidsnota Waterveiligheid 2009–2015
Ministry of Transport Public Works and Water Management (2006) Beleidslijn grote rivieren (policy guideline major rivers)
Ministry of Water Land and Air Protection (2004) Flood hazard area land use management guidelines. Province of British Columbia
Munich Re (2014) Natural catastrophes 2013 analyses, assessments, positions. Munich Re, Munich
Neuvel JMM, Van den Brink A (2009) Flood risk management in Dutch local spatial planning practices. J Environ Plan Manag 52(7):865–880. doi:10.1080/09640560903180909
Fraser Basin Council (and Northwest Hydraulic Consultants Ltd) (2006) Lower Fraser River hydraulic model—summary of results. Fraser Basin Council, Vancouver
OECD (2006) OECD Studies in Risk Management: Japan Floods. OECD
Olfert A, Schanze J (2008) New approaches to ex-post evaluation of risk reduction measures: the example of flood proofing in Dresden, Germany. In: Samuels P, Huntington S, Allsop W, Harrop J (eds) Flood risk management: research and practice. Taylor & Francis Group, London, pp 1173–1184
Olsson P, Folke C, Berkes F (2004) Adaptive comanagement for building resilience in social–ecological systems. Environ Manage 34(1):75–90
Petrow T, Thieken AH, Kreibich H et al (2006) Improvements on flood alleviation in Germany: lessons learned from the Elbe flood in august 2002. Environ Manage 38:717–732
Pielke RA (1999) Nine fallacies of floods. Clim Change 42:413–438
Pieterse N, Tennekes J, Van de Pas B et al (2013) Flood hazard mapping for spatial planning: conceptual and methodological considerations. In: Klijn F, Schweckendiek T (eds) Comprehensive flood risk management. Taylor & Francis Group, London, pp 779–784
Pinter N (2005) One step forward, two steps back on U.S. Floodplains. Science 308(5719):207–208
PLANAT (National Platform for Natural Hazards) (2004) The cycle of integrated risk management. http://www.planat.ch. Cited 28 Oct 2004
Plapp T, Werner U (2006) Understanding risk perception from natural hazards: examples from Germany. In: Amman WJ, Dannenmann S, Vulliet L (eds) RISK 21—coping with risks due to natural hazards in the 21st century. Taylor & Francis Group, London, pp 101–108
Pottier N (2000) Risques d'inondation, reglementations et territoires. Hommes et Terres du Nord 2:93–101
Pottier N (2002) Gestion du risque d'inondation et maitrise de l'urbanisation dans le val de Saone. In: Bravard JP, Combier J, Commercon N (eds) La Saone: Axe de civilisation. Presses Universitaires de Lyon, pp 197–213
Pottier N, Penning-Rowsell E, Tunstall S et al (2005) Land use and flood protection: contrasting approaches and outcomes in France and in England and Wales. Appl Geogr 25:1–27
Poussin JK, Bubeck P, Aerts JCJH et al (2012) Potential of semi-structural and non-structural adaptation strategies to reduce future flood risk: case study for the Meuse. Nat Hazards Earth Syst Sci 12:3455–3471. doi:10.5194/nhess-12-3455-2012
Poussin JK, Botzen WJ, Aerts JC (2014) Factors of influence on flood damage mitigation behaviour by households. Environ Sci Pol 40:69–77

Raschky PA (2008) Institutions and the losses from natural disasters. Nat Hazards Earth Syst Sci 8:627–634. doi:10.5194/nhess-8-627-2008
Rawls J (1973) A theory of justice. Harvard University Press, Massachusetts
Reynaud A, Aubert C, Nguyen MH (2013) Living with floods: protective behaviours and risk perception of Vietnamese households. Geneva Pap 38:547–579
Rogers RW (1975) A protection motivation theory of fear appeals and attitude change. J Psychol 91:93–114
Rogers RW (1983) Cognitive and physiological processes in fear appeals and attitude change: a revised theory of protection motivation. In: Cacioppo BL, Petty RE (eds) Social psychophysiology: a sourcebook. Guilford Press, London
Seifert I, Botzen WJW, Kreibich H et al (2013) Influence of flood risk characteristics on flood insurance demand: a comparison between Germany and the Netherlands. Nat Hazards Earth Syst Sci 13(7):1691–1705
Shrubsole D (2007) From structures to sustainability: a history of flood management strategies in Canada. Int J Emerg Manag 4(2):183–196
Siegrist M (2013) The necessity for longitudinal studies in risk perception research. Risk Anal 33(1):50–51
Siegrist M, Gutscher H (2006) Flooding risks: a comparison of lay people's perceptions and expert's assessments in Switzerland. Risk Anal 26(4):971–979
Siegrist M, Gutscher H (2008) Natural hazards and motivation for mitigation behaviour: people cannot predict the affect evoked by a severe flood. Risk Anal 28(3):771–778
Sigmaplan (2014) Meet the Scheldt—The Sigma Plan: roadmap to an invigorated Scheldt region. Waterwegen en Zeekanaal NV, Sea Scheldt Department, Antwerp. http://www.sigmaplan.be/en/publications/general-brochures/general-sigma-brochure
Smith DI (1981) Actual and potential flood damage: a case study for urban Lismore, NSW, Australia. Appl Geogr 1:31–39
Smith DI (1994) Flood damage estimation—a review of urban stage-damage curves and loss functions. Water Sa 20(3):231–238
Stadt Köln (1994) Hochwasser-Merkblatt für Bewohner gefährdeter Gebiete der Stadt Köln, Köln
Stalenberg B, Vrijling J (2006) Interaction between Dutch flood protection and urbanization. International Symposium of Lowland Technology, Saga
Takao K, Motoyoshi T, Sato T et al (2004) Factors determining residents' preparedness for floods in modern megalopolises: the case of the Tokai flood disaster in Japan. J Risk Res 7(7–8):775–787
Te Linde AH, Bubeck P, Dekkers JEC et al (2011) Future flood risk estimates along the river Rhine. Nat Hazards Earth Syst Sci 11:459–473
Thieken AH, Petrow T, Kreibich H et al (2006) Insurability and mitigation of flood losses in private households in Germany. Risk Anal 26(2):383–395
Thieken AH, Kreibich H, Muller M et al (2007) Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002. Hydrol Sci J 52(5):1016–1037
Thieken AH, Cammerer H, Dobler C et al (2014) Estimating changes in flood risks and benefits of non-structural adaptation strategies—a case study from Tyrol Austria. Mitig Adapt Strateg Glob Chang. doi:10.1007/s11027-014-9602-3
MURL (2000) Hochwasserfibel—Bauvorsorge in hochwassergefährdeten Gebieten. Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen (MURL), Düsseldorf
USACE (US Army Corps of Engineers (1995) Flood proofing. Washington, DC, EP:1165-2-314
USACE (US Army Corps of Engineers) (1996) Engineering and design. Risk-based analysis for flood damage reduction studies. Washington, DC, Manual No. 1110-2-1619
Van Vliet M, Aerts JCJH (2014) Adaptation to climate change in urban water management—flood management in the Rotterdam Rijnmond Area. In: Grafton RQ, Daniell KA, Naugeset C (eds) Understanding and managing urban water in transition. Springer, Dordrecht
VAwS-Baden-Württemberg (2005) Verordnung des Ministeriums für Umwelt und Verkehr über Anlagen zum Umgang mit wassergefährdenden Stoffen und über Fachbetriebe, Anlagenverordnung Wassergefährdende Stoffe—VawS, Baden-Württemberg
VAwS-Bayern (2008) Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen und über Fachbetriebe, Anlagenverordnung-VAwS, Bayern
VAwS-Hessen (2006) Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen und über Fachbetriebe, Anlagenverordnung-VAwS, Hessen
BMVBW (2002) Hochwasserschutzfibel—Planen und Bauen von Gebäuden in hochwassergefährdeten Gebieten. Bundesministerium für Verkehr-, Bau- und Wohnungswesen (BMVBW), Berlin
Wachinger G, Renn O, Begg C et al (2013) The risk perception paradox—implications for governance and communication of natural hazards. Risk Anal 33(6):1049–1065

Wanczura S (2005) Country report—Poland. In: Greiving S, Fleischhauer M, Wanczura S (eds) Report on the European scenario of technological and scientific standards reached in spatial planning versus natural risk management. ARMONIA Project, Dortmund

Wasserhaushaltsgesetz (2009) Gesetz zur Ordnung des Wasserhaushalts (WHG)

Watt WE (2000) Twenty years of flood risk mapping under the Canadian national flood damage reduction program. In: Marsalek J et al (eds) Flood issues in contemporary water management. Kluwer Academic Publishers, Dordrecht, pp 155–165

Wilson E (2006) Adapting to climate change at the local level: the spatial planning response. Local Environ 11(6):609–625

Wind HG, Nierop TM, De Blois CJ et al (1999) Analysis of flood damages from the 1993 and 1995 Meuse floods. Water Resour Res 35(11):3459–3465

Wisner B (1998) Marginality and vulnerability: why the homeless of Tokyo don't 'count' in disaster preparations. Appl Geogr 18:25–33

Zimmerman M, Pozzi A, Stoessel F (2005) Vademecum—hazard maps and related instruments, The Swiss system and its application abroad, PLANAT, Bern, http://162.23.39.120/dezaweb/ressources/resource_en_25123.pdf