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After the extreme flood in 2002: changes in preparedness, response and recovery of flood-affected residents in Germany between 2005 and 2011

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Abstract

In the aftermath of the severe flood in August 2002, a number of changes in flood policies were launched in Germany and other European countries aiming at an improved risk management. The question arises, whether these changes have already an impact on the residents' capabilities of coping with floods and whether flood-affected private households are now better prepared than in 2002. Therefore, computer-aided telephone interviews with private households in Germany that suffered from property damage due to flooding in 2005, 2006, 2010 or 2011 were performed and analysed with respect to flood awareness, precaution, preparedness and recovery. The data were compared to a similar investigation after the flood in 2002.

After the flood in 2002, the level of private precaution increased considerably. One contribution factor is that a larger part of people knew that they are at risk of flooding. Yet this knowledge did not necessarily result in building retrofitting or flood proofing measures. The best level of precaution was found before the flood events in 2006 and 2011. This might be explained by more flood experience and overall greater awareness of the residents. Still, costs and damage avoiding benefits of these measures have to be communicated in a better way.

Early warning and emergency response were substantially influenced by flood characteristics. In contrast to flood-affected people in 2006 or 2011, people affected by flooding in 2005 or 2010 had to deal with shorter lead times, less time to take emergency measures; consequently they suffered from higher losses. Therefore, it is important to further improve early warning systems and communication channels, particularly in hilly areas with fast onset flooding.

1 Introduction

In August 2002, a severe flood event occurred in Central Europe (Germany, Austria, the Czech Republic and Slovakia). Heavy precipitation due to a Vb weather system with record breaking amounts, e.g. of 312 mm within 24 h had been observed at the gauging station Zinnwald-Georgenwald in the Erzgebirge, Germany, and resulted in high discharges and water levels in the rivers Elbe and Danube and some of their tributaries (see Ulbrich et al., 2003; Engel, 2004). The high hydraulic impact led to the activation of dam spillways as well as to overtopping and breaching of embankments in many places. Among other things, missing or incomplete flood warnings, bad maintenance of flood protection structures as well as a lack of knowledge about adequate behaviour were identified as weaknesses of the flood risk management (DKKV, 2003; Thieken et al., 2007). Altogether, 21 people were killed in Germany and the total damage amounted to €11 600 million (Thieken et al., 2006). This amount exceeded the damage of former disastrous events by far and despite a similar flood event in June 2013, it is still the highest damage record in Germany (EM-DAT, 2014). After the flood in 2002, many activities were launched on the administrative and legislative levels (see DKKV, 2003). Particularly, the German act on precautionary flood protection (*Artikelgesetz zur Verbesserung des vorbeugenden Hochwasserschutzes*) and the European Floods Directive (2007/EC/60; EC, 2007) were important policies, which also indicate a shift from a pure technical-oriented flood defence towards a more integrated flood risk management that also considers non-structural measures to minimise adverse effects of flooding. In general, flood risk management focuses on three aspects (Vis et al., 2003): (1) flood abatement with the aim to prevent peak flows, e.g. by an improvement of the water retention capacities in the whole catchment, (2) flood control that is aimed at preventing inundation by structural measures, e.g. embankments or detention areas and (3) flood alleviation with the goal to reduce flood impacts by non-structural measures (Parker, 2000; de Bruijn, 2005). In the latter, preventive, precautionary and preparative measures can be distinguished. Prevention is aimed at completely avoiding damage in hazard-prone areas, e.g. by land use regulation. Precaution and preparation help to limit and manage adverse effects of a catastrophe and to build up coping capacities by flood-resilient design and construction, development of early warning systems, awareness campaigns, education and training etc. (e.g. Vis et al.,

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2003; DKKV, 2003; PLANAT, 2004; de Bruijn, 2005). If damage occurs despite of these measures, risk transfer mechanisms such as flood insurance help to accelerate recovery (see e.g. Thieken et al., 2006; Schwarze et al., 2011).

The success of precautionary and preparatory measures depends to a high degree on the risk awareness and preparedness of flood-affected residents. Surveys which were performed a few months after the flood in 2002 (Thieken et al., 2005; Kreibich et al., 2007) revealed that flood-affected households and companies had difficulties to cope with the flooding and suffered from high financial losses, particularly along the river Elbe and its tributaries. In these areas, only 3.6 and 7.4 %, respectively, had experienced flooding in the ten years prior to the event (Thieken et al., 2007). Hence, flood risk awareness was at a low level.

After the flood in 2002, a substantial increase in the implementation of precautionary measures was detected for private households and companies (Thieken et al., 2007; Kreibich et al., 2005, 2007, 2011). Therefore, the question arises whether German residents at risk of flooding are now better able to cope with flooding than they were in 2002. Since the above-mentioned changes in European and national flood policies have not only been effective in affected regions of 2002, but in all of Germany, flood risk awareness and preparedness should have increased in general, i.e. also in areas that did not experience flooding recently. This aspect will be addressed in this paper by investigating coping capacities of private households during four flood events between 2005 and 2011 that occurred in different regions. Analogue to the paper of Thieken et al. (2007), the disaster management cycle will be used as framework for the analysis. The cycle has widely been used by international and national organisations and various versions have been published (e.g. Silver, 2001; DKKV, 2003; PLANAT, 2004; FEMA, 2004; Kienholz et al., 2004). It distinguishes three (or four) phases: (emergency) response, recovery, (risk analysis and assessment) and disaster risk reduction. During the event, immediate measures are undertaken with the priority to limit adverse effects and the duration of the event (response phase). After the event, the affected society starts to repair damage and to regain the same or a similar standard of living than

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before the disaster happened (recovery phase). Ideally, the recovery phase is already accompanied by an event and risk analysis that leads to a period of disaster risk reduction, in which measures that are aimed at minimising the vulnerability of people and their assets are planned and implemented (Kienholz et al., 2004).

This paper aims to reveal how residents in different regions of Germany were prepared to recent flooding, how they responded to the hazardous events, how they suffered in terms of financial damage and recovered as well as what they changed in precaution after having experienced a flood. We focus on four flood events in Germany that happened in August 2005, March/April 2006, August 2010 and January 2011, respectively. The four events affected different catchment areas: in 2005 and 2006, flooded regions were similar to those in 2002. In 2010 and 2011, however, flooding occurred in regions, where less people experienced a flood within the last ten years, although in some areas in the Rhine catchment the level of precaution is assumed to be high (Bubeck et al., 2012b). In addition, these floods were triggered by different weather patterns. While flooding in (2002) 2005 and 2010 was due to heavy precipitation in connection with a Vb-weather type, floods in 2006 and 2011 were characterised by a "rain on snow" mechanism. Since the level of preparedness and reaction might also depend on the flood characteristics, the four flood events will be described in more detail in the next section. In Sect. 3, data and methods of the analysis will be introduced. Then Sect. 4 focuses on the results of the analyses, while Sect. 5 offers some conclusions on what could further be done to stipulate private precaution and disaster preparedness.

2 The four flood events

In order to provide a basis for the interpretation of the flood characteristics on the reaction and coping capacities of affected residents, the four flood events are described in this section. A description of the 2002 event that serves as reference (see below) was already given in the introduction. Table 1 summarizes hydro-meteorological conditions

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and financial damages of all flood events. In Fig. 1 the mentioned rivers and cities can be found.

2.1 July/August 2005

A considerable flood affected the German part of the Danube catchment in August 2005. Cyclone "Norbert" closely followed the track of a Vb-weather system and induced the advection of moist air from sub-tropical regions to Switzerland, northern Italy, Austria and southern Germany. The encounter with cold air masses and an orographic uplift at the north face of the Alps led to prolonged rainfall with notably high amounts within 12 to 24 h (e.g. 216 mm in 24 h on 22 August 2005 Balderschwang; LfU, 2007). As a result, the alpine foothills were affected by flash floods characterized by a rapid increase in discharges and water levels. Inundations occurred both along the river Danube and its southern tributaries. Return periods of maximum discharges were classified to less than 1 in 100 years at the Iller, Schmutter, Amper, Inn and Isar rivers and to 1 in 20 to 50 years at the rivers Lech, Loisach and Mangfall. At the Danube river, highest return periods occurred at Ingolstadt and Kelheim in the range of 1 in 20 to 50 years (LfU, 2007). Flood protection measures as well as operation of dams and retention areas effectively reduced the flood impact. The total economic damage was estimated to about €175 million in Germany (Kron, 2009). Damage to infrastructure amounted to €50 million, damage to private households and to the commercial sector amounted to about €70 million (LfU, 2006).

2.2 March/April 2006

The river flood in spring 2006 mainly occurred in the Elbe catchment. Due to exceptionally heavy snowfall during the winter of 2005/2006, the amount of water stored as snow was about 2.4 billion m^3 at the beginning of 2006 in the upper Elbe catchment (Korndörfer et al., 2006). At the end of March, temperatures rose rapidly to 5 to 15 °C leading to a complete snowmelt within one week also in the upper parts

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of the middle hills (BfG, 2006). Additionally, heavy rainfall occurred in the whole upper catchment area of the river Elbe, e.g. upstream of the Dresden gauge, due to several westerly cyclones. The water levels in the Elbe catchment increased significantly on 26 March 2006 and relatively long lasting plateau like flood waves developed (IKSE, 2007). On 4 April 2006, peak flows were reached at the Schöna and Dresden gauges and on 5 April at the Torgau and Wittenberg gauges. Further downstream peak flows were reached on 9 April at the Hitzacker, Neu Darchau and Geesthacht gauges. Water levels decreased slowly; only after 4 May 2006 all water levels along the Elbe River had dropped below the flood warning levels at the warning gauges (IKSE, 2007).

At the Dresden gauge, the flood discharge in 2006 (2923 $m^3 s^{-1}$) was the second highest discharge since 1940, after the discharge in August 2002 (4580 $m^3 s^{-1}$), although its return period was estimated to only about 15 years (Kreibich and Thieken, 2009). Since no levee breaches occurred in the upper and middle reaches of the Elbe River and since the retention areas at the Havel confluence were not activated, the flood situation downstream of the Havel confluence was comparable to or even worse than in August 2002. For instance, at the Neu Darchau gauge, the flood discharge of 3600 $m^3 s^{-1}$ in 2006 was the second highest in 100 years and exceeded the 2002 flood discharge of 3400 $m^3 s^{-1}$ (BfG, 2006). Accordingly, resulting flood damage in Dresden was minor and thus significantly lower than in 2002 (Kreibich and Thieken, 2009). In contrast, the city of Hitzacker in Lower-Saxony was heavily affected in 2006, flooding of the whole city centre was more severe than in 2002 (IKSE, 2007). The total resulting damage in Germany was estimated to be €120 million (Kron and Ellenrieder, 2008).

2.3 August 2010

Three heavy rainfall events in August and September 2010, of which the first one on 6/7 August was the most intense one, resulted in extreme floods in the Odra and Elbe catchments (Walther et al., 2013). The heavy rainfall resulted from cyclone "Viola" a Vb weather system, particularly in the Iser- and Lausitzer mountains where maximal hourly rainfall amounted to 60 mm in the morning of 7 August (Jelonek et al., 2010). On 15/16

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August a cold front of a depression area moved in northern direction resulting again in heavy rainfall in the south-eastern part of Saxony in Germany. End of September the low-pressure system "Lya", a Genoa Cyclone Type Vb weather system, created a rainband with heavy precipitation stretching over Austria, the Czech Republic and Germany up to the Baltic Sea.

At the river Lausitzer Neiße as well as at the tributaries of the upper Elbe (e.g. Kirnitzsch River) highest peaks occurred during the first flood wave beginning of August, with maximum discharges classified as 500 year flood events (Walther et al., 2013). The flood situation was aggravated significantly due to the breach of the dam Niedow at the Witka River a tributary of the river Lausitzer Neiße on 7 August (Jelonek et al., 2010). In the upper parts of the Schwarze Elster and Spree catchments, the highest peaks occurred at the beginning of August with return intervals of up to 500 years at the Spree and up to 200 years at the Schwarze Elster. At their lower reaches, the highest peaks occurred at the end of September with return intervals of 50 to 100 years (Walther et al., 2013). Particularly high damage occurred in the upper reaches of the Lausitzer Neiße and Spree as well as at the Mandau River. The total resulting damage in Germany was reported to be €839 million (EC, 2014).

2.4 January 2011

Processes leading to flooding in January 2011 were comparable with the flood in 2006, but affected a considerably larger area in Germany. Due to the cold winter with massive snowfall a lot of water was stored as snow in many parts of Germany. An inflow of warm air in combination with heavy rainfall led to a spacious snow melt and a first increase in river discharges between 5 and 6 January 2011. In the following, between 12 and 14 January 2011, large-scale, intense rainfall fell on already saturated soils which led to a second flood wave with water levels above the flood warning levels at many gauges (Axer et al., 2012). Nearly all large catchments in Germany were affected, e.g. the catchments of the Rhine, the Danube, the Weser and the Elbe (Axer et al., 2012). Particularly high discharges occurred at the rivers Main and Saale and in

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the upstream part of the Weser catchment. In Saxony-Anhalt at the rivers Elbe, Saale, Havel, Schwarze Elster, Weiße Elster, Wipper and Bode water levels increased to alarm level 4 around 15 January (LHW, 2011). Flooding occurred and resulted in damage in the catchments of the Rhine, the Danube, the Weser and the Elbe. However, despite the many affected catchments, disastrous damage did not occur. The total damage was estimated to be more than €100 million in Germany (Axer et al., 2012).

3 Data and methods

3.1 Procedure of sampling flood-affected private households

The data set contains information collected by computer-aided telephone interviews with private households that suffered from property damage due to flooding in 2002, 2005, 2006, 2010 or 2011 (Fig. 1). In the following, the flood events 2005, 2006, 2010 and 2011 are referred to as study subsets, and the 2002 event as reference subset (Table 2). Since the compilation of the reference data set was already described by Thieken et al. (2005, 2007), only the collection of the study subsets is described.

On the basis of flood reports or press releases as well as with the help of flood masks derived from radar satellite data (DLR, Centre for Satellite Based Crisis information, www.zki.dlr.de) lists of inundated streets were compiled for each flood event. These lists served as a basis to select telephone numbers of all potentially affected residents/households from the public telephone directory. Computer-aided telephone interviews were undertaken with the VOXCO software package (www.voxco.com) by the Explorare market research institute (www.explorare.de), once in November/December 2006 and once in February/March 2012 (Table 2). Always the person in the household who had the best knowledge about the flood event was questioned.

In total, 461 interviews were undertaken in 2006, of which 305 interviewed households had been affected in 2005 and 156 in 2006. The second campaign resulted in 658 interviews with 349 households affected in 2010 and 209 households affected in 2011 (Table 2). The remaining 100 interviews were undertaken with households affected by torrential rain in the city of Osnabrück in August 2010; however, these data are not included in the current analyses. The respective numbers and shares of interviews referring to the affected river catchments are listed in Table 3.

3.2 Contents of the questionnaire and data processing

For the two campaigns the questionnaire presented in Thieken et al. (2005, 2007) was slightly adapted. Altogether, the questionnaires contained about 180 questions addressing the following topics: flood impact, contamination of the flood water, flood warning, emergency measures, evacuation, cleaning-up, characteristics of and damage to household contents and buildings, recovery of the affected household, precautionary measures, flood experience as well as socio-economic variables. For our analyses, we selected only those variables which were presented in Thieken et al. (2007) for the flood event in 2002 in order to enable a consistent comparison of the different flood events (Table 4). These variables differed significantly in the regions that were investigated by Thieken et al. (2007) and are hence assumed to provide reasonable information for the comparison of different flood events.

In a number of questions people were asked to assess qualitative or descriptive variables on a rank scale from 1 to 6, where "1" described the best case and "6" the worst case. The meaning of the end points of the scales was given to the interviewee (see Table 4). The intermediate ranks could be used to graduate the evaluation.

To analyse the amounts of financial loss, some assumptions had to be made. In the survey, some respondents did not put a precise figure on their financial damage, but indicated for example that they had "hardly suffered damage" or "only electricity costs for operating the pump". In order to quantify these kinds of damages, a flat-rate loss of €250 had been attributed to such cases. This amount was determined by the authors and represents approximately the average deductible for natural hazard insurances in

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Germany. However, for the calculation of the average and median losses, the cases with an added flat-rate value were not taken into account.

Regarding the recovery analyses it should be noted that due to the different time lags between the surveys and the respective flood events (see Table 2), the results could not be simply compared with each other. To ensure a level playing field, only data of those flood events could be compared, which were collected after a similar time lag. This applied to the years 2002 and 2006, where respondents were interviewed 7 to 9 months after the flood event; and also to 2005, 2010 and 2011, where the corresponding time lags were between 13 and 19 months (compare Table 2).

4 Results and discussion

4.1 General characteristics of the four study subsets

The characteristics of the four study subsets and the reference dataset, statistics of the flood impact, socio-economic variables and flooding experienced prior to the events under study are summarised in Table 5.

In all four study subsets, respondents aged between 50 and 60 years on average, though interviewees in 2010 and 2011 were slightly older. These figures are considerably higher than the average age of the German male or female population (BiB, 2014a). Maybe this hints to a methodological problem that has emerged recently. Only households of the central telephone register can be included in the sample. Due to the increasing use of mobile phones, elderly people and homeowners with landlines may tend to be overrepresented in the sample. Further, in 2005 or 2006 more people had a high school or university degree than in 2010 or 2011. Yet in 2011, the share of households with a net income of less than €1500 was smallest, more people owned the house or flat, which was in addition much larger in terms of mean living area per person than in the other subsets. Mean household size was about the same in all years, merely

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slightly bigger in 2005. The socio-economic results of the reference subset collected after 2002 were in general in the same range as the results of the other study subsets.

Concerning flooding experienced before the respective event, considerable differences between individual study subsets could be found, which was particularly evident for the study subset 2010. The percentage of respondents who had experienced at least one previous flood was much higher in 2006 and 2011 with 83 and 78 %, respectively, than in the years 2005 and 2010 with 55 and 52 %, respectively. In 2005, 2006 and 2011, between 74 and 89 % of these flood-affected interviewees stated that they had experienced flooding within the last ten years. In contrast, this was only the case for 58 % of flood-affected respondents in 2010.

It is furthermore striking that among those respondents who had never experienced a flood, a large group of people nevertheless knew about their risk. In the study subsets of 2005, 2006 and 2010, this proportion ranged between 41 and 52 %; in 2011 it was even 69 %.

Looking back at the reference subset 2002, previous flood experience was considerably lower than in subsequent flood years. At that time, only 22 % of respondents had experienced one flood before and 60 % of those people experienced a flood within the last ten years. The share of people who had not experienced a flood, but at least knew about being at risk amounted to 31 %. Overall, a larger part of respondents of the study subsets had a lot more experience with flooding and also knew to a great extent that they are at risk than respondents of the reference subset 2002. Though, the results of 2010 stand out from the other flood years, indicating generally lower risk awareness.

The flood impact differed between all four events. As outlined in Sect. 2, the flood events in 2005 and 2010 had been both typical summer floods due to local heavy rainfall events with fast reacting runoff processes and can therefore be classified as rapid onset flood, whereas floods in 2006 and 2011 occurred in spring/winter at larger scale with slower runoff processes and can be classified as river floods. Hence, the mean flood duration in the study subsets 2005 and 2010 was considerably shorter than

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in the study subsets 2006 or 2011. The impacts of the flood regarding mean water level and contamination were most severe in the study subset 2010, which also reflects the severity of the flood event as described in Sect. 2.3. In comparison, during the 2002 summer flood, both flood characteristics occurred: river floods occurred along the main rivers and rapid onset floods in the headwaters (see Ulbrich et al., 2003). The resulting mean flood duration was comparable to the study subset of 2006. However, the mean water level and contamination had been still much worse than in any of the other study subsets.

4.2 Preparedness before the flood events

Private preparedness before a flood event is an important component of flood risk management as it can have a significant effect on flood loss mitigation. It includes three types of precautionary measures: (1) information and behavioural precaution, e.g. collecting information about the flood hazard and protection as well as participation in networks, (2) flood proofing and retrofitting measures, e.g. adapting the building structure or usage of the premises and furniture, reconstructing the heating system or purchasing water barriers, and (3) risk precaution, e.g. contracting a flood insurance (LAWA, 1995; ICPR, 2002; DKKV, 2003; BVMBS, 2008; Kreibich et al., 2005, 2011).

With respect to precautionary behaviour before the respective flood event of the study subsets, more than 90 % of all respondents performed at least one precautionary measure; in contrast, only 7 % did not carry out any measure at all. Generally, interviewees mostly gathered information about the flood hazard and how to protect themselves (58 %) as well as participated in networks (43 %) (Fig. 2). Although collection of information is an important first step, these measures do not lead to damage mitigation in the first place. This is only possible if the knowledge is further translated into real action. Hence, damage reduction is achieved exclusively through precautionary measures like flood-proofing and building retrofitting or emergency measures (see ICPR, 2002; Kreibich et al., 2005). With regard to these flood-proofing and building retrofitting actions, adaptation of interior equipment (43 %) and building

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use (39 %) were more often performed by the respondents of the study subsets than any other precautionary measure, e.g. replacement of oil heating, purchasing water barriers or sealing the basement.

When comparing the individual study subsets, however, clear differences in the performance of measures can be identified. Highest percentages of households that undertook actions before the flood were most frequently recorded in 2011. Acquisition of information, adaptation of building use and furnishing as well as purchasing water pumps and avoiding environmental contamination were carried out by more than 60 % of respondents. All other measures, however, were performed by less than 40 % of households interviewed. Second-best prepared were the people affected in 2006. Before 2005, most of the measures were performed the least. Only the oil heating was most frequently replaced. The reason might be that in 2005, especially the Danube catchment was affected by the flood. These people had already suffered severe flood damage in 1999 due to oil contamination and have subsequently retrofitted their heating system (Müller, 2000). In addition, in 2005 more buildings were heated with oil (45 %) than in the other three study subsets (2006: 23 %, 2010: 24 %, 2011: 35 %).

It is furthermore striking that insurance against damage due to flood hazards was more often contracted by people interviewed in 2010 (57 %) and 2006 (39 %) than by people interviewed in 2005 (27 %) or 2011 (25 %). This fact must be seen in the context of the insurance history in Germany. In the former states of the German Democratic Republic, which were primarily affected by floods in 2010 and 2006, flood insurance was included in the household contents policy. Today, many local people still have similar contracts. In the West German states, excluding Baden-Wuerttemberg, flood insurance is less common and was introduced only in 1994 as a voluntary supplementary contract to the building insurance (Thieken et al., 2006; GDV, 2013).

Overall, the state of private precaution was clearly higher before recent events than before the reference event in 2002, where most respondents relied on flood insurance to counterbalance financial losses (41 %) as well as gathered information

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about precaution (30 %). Flood proofing and retrofitting measures were carried out by less than 15 % of the respondents.

Furthermore, people were asked how they perceived the general effectiveness of private precautionary measures. Answers should be evaluated on a scale ranging from 1 (= private precautionary measures can reduce flood damage very effectively) to 6 (= private precautionary measures are totally ineffective for flood damage reduction). The results of the study subsets show that the perceived effectiveness of measures rises almost steadily from year to year (Fig. 3). In 2005, 47 % of respondents rated the effectiveness 1 or 2. In 2006 and 2010 the respective value was 52 %, and even 67 % in 2011. By contrast, flood-affected people of the reference subset 2002 perceived the effectiveness generally lower. Merely 39 % of the respondents chose a score of 1 or 2 (Fig. 3).

Altogether it can be concluded that today people are much better prepared in case of flooding than they were in 2002 and confidence in the effectiveness of precautionary measures has steadily increased. However, on the basis of the four study subsets, no constant improvement of private precaution could be identified in the course of time. In fact, the level of precaution before the flood event in 2011 and 2006 was strikingly higher compared to that before 2005 or 2010. One explanation for these differences between the four study subsets might be the difference of personal flood experiences. Highest percentages of performed precautionary measures before 2011 and 2006 are associated with the most previous flood experience (see also Table 5). In their review, Bubeck et al. (2012a) list several studies, which also found a (weak) positive correlation between the two factors personal flood experience and performance of precautionary measures (Grothmann and Reusswig, 2006; Siegrist and Gutscher, 2006; Lindell and Hwang, 2008; Kreibich et al., 2011). However, there are also studies in which this relationship was not significantly confirmed (Takao et al., 2004; Thieken et al., 2007). Besides the frequency of flood experience, the time lag to the last experienced flood event is also assumed to be a relevant factor for mitigation behaviour, as flood awareness constantly decreases again over time. According to ICPR (2002), flood awareness diminishes within seven years and only remains for a longer period after catastrophic disasters. Before the flood event in 2010 for example, many respondents in the Oder–Neisse catchment had only been rarely affected by a flood, which in addition dated back several years. This also applied especially to people who were affected by the severe flood event in 2002. In the light of the above, the lower percentages of performed precautionary measures before 2010 or 2002 might be explained. In this context it is noteworthy, however, that by far most respondents affected by the flood in 2011 knew that they live in a flood-prone area, although they did not experience a previous flood. This reflects a profound awareness of the flood risk in this area and might be a reason for the people's outstanding preparedness before 2011. Yet, the knowledge of one's own potential flood risk and the information about protection did not necessarily result in technical or structural building retrofitting or flood proofing measures. Even before the flood event in 2011, these measures were carried out to a lower extent, though some of these measures were only given to homeowners (see Fig. 2). Nonetheless, the benefits and cost savings of these actions still have to be communicated in a better way.

4.3 Warning and response

Damage mitigation not only depends on long-term preparedness, but also on people's flood awareness and how they react at the time of the approaching flood.

4.3.1 Flood warning and lead time

To respond to a flood, people need to be made aware of the risk. Early warning systems and communication play a decisive role in this context. However, people's response to warnings is above all dependent on the warning lead time, which in turn is strongly dependent on the catchment size and shape as well as on flood characteristics. Longer lead times of several days can be provided in the middle to lower reaches of large river catchments due to the temporally extended flow of the flood wave (river flood).

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In contrast, lead times for small mountain rivers in the upper basins are more in the order of few hours up to one day because of fast reacting runoff processes (medium to rapid onset floods) (Bürgi, 2002; Younis et al., 2008; Golding, 2009). Accordingly, spatial information dissemination and warning quality can vary a lot due to these characteristics.

This linkage is also reflected in the flood warning results obtained in this study. As described in Sect. 2, catchment and flood characteristics of the four flood events differed, with the result that the 2005 and 2010 flood events were classified as rapid onset floods and the 2006 and 2011 events as river floods. Hence, there were considerable differences with respect to the respective average lead times. In 2010 and 2005, mean lead times of 11 and 16 h were reported, respectively, whereas respondents in 2011 and 2006 had on average at least 23 and 40 h time, respectively, to prepare for the flood. The mean lead time in the reference subset 2002 was about in the range of 2006 (Table 6). At that time, however, there was also a spatial heterogeneity with regard to the flood processes (see Thieken et al., 2007).

The longer lead times had a positive effect on the dissemination of flood information in the study subsets. Therefore, best spreading of flood information was achieved in 2011 and 2006. Only 6 % (2011) and 12 % (2006) of the people had not been warned, in contrast to 2005 and 2010, where these values reached 27 % and even 32 %, respectively (Table 6). Within the context of warning sources, warnings by authorities are very important as they are considered trustworthy. Most respondents received an official warning in 2011 (45 %); however, again due to lack of time, least percentage of respondents received it in 2010 (33 %).

With respect to the percentage distribution of all warning sources, Thieken et al. (2007) found for the reference year 2002 that responses were already very heterogeneous within the spatial distribution of the 2002 flood event. When comparing the results of 2002 to the average percentage of all study subsets, it can be seen that the respective values do not exhibit any trend, but are rather different (Table 6). In view of that, the regional topography and flood characteristics appear to be the most determining factors for the warning sources.

4.3.2 Content of warnings and reaction capabilities

To receive a flood warning is just one of the key preconditions to take emergency measures. As mentioned above, it also depends on the quality of warning content. The information content of flood warnings by authorities was therefore investigated in further detail. The results revealed that warnings were comprehensive in all investigated study subsets. The comparison of the individual subsets showed that in 2010 information about residential areas at risk (52 %), advice for damage reduction (49 %), evacuation (29 %) and levee breaches (17 %) were reported more often than in any other study subset (Table 7). Other warning contents like information about maximal water level (68 %), time to peak water level (58 %) or information about diversions or road blockings (27 %) were most often included in 2006 or 2011.

In summary, however, no clear information content improvement can be derived from the study subsets compared to the reference year 2002. Again, it is assumed that the quality of warnings depends to a high degree on the flood characteristics, but also on the number of previously experienced floods as authorities, that disseminate warning information certainly improve with an increasing number of flood events. Furthermore, flood warnings are the responsibility of the individual federal states so that there might be also regional differences in the quality of warnings. Moreover, it has to be acknowledged that the number of valid answers was rather small (see Table 7).

Respondents who received an official flood warning were furthermore asked to evaluate their knowledge to protect themselves and their households, based on the obtained warning. On a scale from 1 (= I knew exactly what to do) to 6 (= I had no idea what to do), approximately 67 % (2005), 81 % (2006) and 85 % (2011) of the study subset interviewees responded 1 or 2 (Fig. 4). Merely in 2010 this share was 50 %. However, the corresponding figure of the reference subset 2002 was even lower (28 %).

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The data reveal that the awareness of emergency preparedness of flood-affected residents had considerably increased after 2002, also in areas that had not experienced flooding for a longer time, which holds for the subset of 2010 (compare Table 5 and Fig. 4). The question arises whether this knowledge could be used to mitigate damage. Therefore, the next sections deal with emergency measures and resulting losses.

4.3.3 Emergency measures

In case of an imminent flood hazard, flood warnings and emergency measures are predominantly performed to mitigate potential loss and damage (Molinari et al., 2013). On average, more than 50 % of all respondents of the four study subsets performed emergency measures such as putting moveable contents upstairs and driving vehicles to a flood-safe place. Further measures carried out frequently aimed at protecting the building from entering water (e.g. by installing a water pump or mobile barriers) or at safeguarding important documents and valuables. However, data on individual study subsets showed that highest percentages were mostly found for the study subsets 2006 or 2011 (Fig. 5). Merely, gas/electricity was most frequently centrally switched off by public services in 2010.

Looking back at the reference subset 2002, the use of water pumps, redirection of water flow as well as safeguard of domestic animals seemed to be of only little importance in terms of emergency measures. However, this is related to the circumstance that these items were not specifically requested in 2002, but deduced from open answers. In fact, however, more people safeguarded documents and valuables, switched of gas or electricity and protected the building against inflowing water than people in any other investigated study subset. An explanation for this could be that the lower preparedness level in 2002 (see Sect. 4.2.) had to be compensated by an increased performance of emergency measures.

A successful damage reduction not only depends on the general performance of emergency measures, but also on their effectiveness. Therefore, performed emergency

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measures were assessed by respondents according to the effectiveness on a scale ranging from 1 (= very effective) to 6 (= totally ineffective). For the illustration in Fig. 6, the results were averaged for each measure and study year. In general, the performed measures in the study subsets were predominantly evaluated to be effective. Averages ranged from 1.1 to 3.8, whereby "to drive vehicles to a flood-safe place" was the measure with the best evaluations, while "to redirect the water flow" was evaluated by the lowest ranks. Measures aiming at redirecting the water flow and protecting the building against inflowing water were considered rather challenging (Fig. 6). We assume that those actions are often difficult to perform as they require in particular longer time, manpower and know-how. In addition, two different evaluation patterns can be identified within the study subsets. Some measures, e.g. to protect the oil tank or to switch off gas/electricity, show a constant improvement of effectiveness over time, whereas almost all other measures were evaluated as being more effective in 2006 and 2011 than in 2005 and 2010.

In 2002, the general picture was very similar to that of the study subsets. People found it also most difficult to protect their building and household contents, though rated these measures even more ineffective. The evaluation of other emergency measures resulted approximately in the same range as in the other study subsets.

Though, despite the better protection knowledge (in comparison to the reference dataset of 2002), 2005 and 2010 were years in which the highest percentage of people performed no emergency measures (22 and 15 %, respectively). In 2006 and 2011, the fraction of households not performing emergency measures amounted only to 8 % (Table 8).

Like in 2002, the main reason for this fact was lack of time. Respectively, 65 and 56 % of respondents in 2005 and 2010 stated that it was too late to do anything (Table 8). In fact, 45 and 39 % of the people in those years argued that they could have done more if they had been warned earlier. In 2006 and 2011, respective shares were only 23 and 10 % (data not shown).

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In summary, it can be said that the warning sources and contents have not improved continuously over time. Rather, the regional topography and flood characteristics seem to influence the extent of warnings considerably. This is also reflected by the fact that people affected by floods in 2005 and 2010 had to deal with shorter lead times than people in 2006 or 2011. Hence, dissemination and quality of (official) flood warnings was limited, with the result that in 2005 and 2010 less people knew exactly how to protect themselves. In addition, people affected in 2005 or 2010 were less flood experienced (see Table 5) and probably less familiar with safeguarding measures. This lack of time, knowledge and experience not only seems to explain why fewer people performed emergency measures in these two study subsets, but also why most of the emergency measures were evaluated less effectively than in 2006 and 2011. Nevertheless, it is apparent that people, who were officially warned, knew much better how to protect themselves as it was the case in 2002. It can therefore be concluded that the flood response capacity of the people had improved after 2002. However, it is still important to further improve early warning systems and communication channels, especially in hilly areas with rapid onset floods, to enable more people to respond to the threat of a flooding.

4.4 Adverse effects of the flood events

4.4.1 Flood damage

Damages that result from flooding can affect different sectors and may have adverse effects on private households (e.g. buildings, furniture), the economy (e.g. public infrastructure, industrial companies, business interruptions, agriculture), the cultural heritage, the environment, or on the people (e.g. health effects, traumata or even loss of life). These kinds of damages can be classified into direct or indirect damages, which might be further subdivided into tangible or intangible damages (Messner and Meyer, 2006; Merz et al., 2010). In this study, only direct tangible damage to buildings and contents of private households was analysed.

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Looking at all four study subsets, 609 of total 1019 respondents (60 %) suffered damage to residential buildings, 479 interviewees (47 %) suffered damage to household contents, in terms of repair and replacement costs. The comparison of the single study subsets showed that the shares of people that sustained building losses were about in the same range. Highest percentages were found in 2010 (65 %) and lowest in 2005 (52 %). In 2006 and 2011, 56 and 64 % were recorded, respectively. However, striking differences in values can be identified with respect to household damage. Far fewer people were affected by damages in 2006 and 2011 (31 and 23 %, respectively) than in 2005 and 2010 (51 and 64 %, respectively). This reflects the differences in flood characteristics, but also in precaution, warning and response that was described in the previous sections. The proportion of people suffering building damage in the reference subset 2002 amounted to 64 % and was about equal to that in 2010 and 2011. Though, the share of people affected by damage to household contents was highest, reaching 75 % (data not shown).

Tables 9 and 10 list the financial building and household damages per year, respectively. The proportions of minor damages up to €250 (including a flat-rate loss; see Sect. 3) are additionally specified. The median building damage, given in prices as at 2013 by correcting the actual amounts by the building cost index of June 2013 (DESTATIS, 2014a), was highest in 2010 and lowest in 2011, reaching €21 436 and €2112, respectively. The corresponding median loss in 2002 amounted to €30 037 (Table 9). A classification of these damages can be seen in Fig. 7. It is noteworthy that in 2011 the share of damage up to €5000 accounted for about two third of all reported damages. In the other three study years, this proportion did not even cover half of the damages, but higher costs were more often reported.

Median damages of household contents in prices as at June 2013, corrected by the consumer price index (DESTATIS, 2014b) were much lower than building damages. However, highest and lowest losses were again recorded in 2010 and 2011 and amounted to €10 560 and €2069, respectively. The median loss of household contents in 2002 amounted to €10 131 and was comparable to 2010 (Table 10). In contrast to

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the classification of building damages, the share of damages to household contents up to €5000 was highest in the study subsets 2006 (70 %) and 2011 (64 %) and reached nearly 50 % in 2005. Only in 2010, this proportion was merely 33 %, which in turn indicates a large number of higher damages (see Fig. 8).

In summary, the median losses show that highest damages were always recorded in 2010 (and 2005, with regard to household contents) and lowest in 2011 (and 2006, with regard to household contents). This pattern can only be explained by taking into account several factors, e.g. flood characteristics, flood experience and awareness and precaution. Hence, losses were higher the shorter the lead time, the lower the previous flood experience, the lower the knowledge about how to protect oneself and the lower the precaution level. However, these interdependencies apply to damages to household contents, yet are only partly explanatory for building damages.

Besides, the expected trend is that households with lower losses recover faster after the flood. This assumption will be addressed in the following.

4.4.2 Recovery

In this study, the recovery status is a simplified measure for the regained standard of living after a flood event compared to the status before the event; knowing that the recovery process in fact needs to be seen in a more nuanced light and is influenced by several factors (e.g. Whittle et al., 2010).

In the surveys, respondents were asked to assess the state of their building and contents at the time of the interview compared to their state before the flood on a scale from 1 (= building/household contents is completely restored/replaced) to 6 (= still considerable damage to the building/household contents). For the analyses, the investigated flood events were grouped into two groups as described in Sect. 3.2. The comparison between the flood events in 2006 and 2002 after 8–10 months after the flood showed: in 2006, the building and furniture status had been valued at 1 or 2 by 62 % and even 73 % of interviewees, respectively. Thus, people recovered faster than in 2002, where the equivalent shares amounted only to 46 and 59 %, respectively. The

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comparison between the flood events in 2005, 2010 and 2011 after 13–18 months after the floods reveals: although the time interval between the flood 2011 and the survey was the shortest among the three events (13–14 months), respondents always recovered best. 77 % of people stated a very good or good building status. In 2005 and 2010, however, these percentages were 67 and 62 %, respectively. The corresponding shares concerning the recovery of the household contents in 2011, 2010 and 2005 were even higher, reaching 82, 72 and 64 %, respectively.

The expected trend that households with lower losses recover faster after the flood could be confirmed for building damages and partly for furnishing damages, as can be clearly seen in the results of the study subset 2011. However, the amount of loss is not the only factor that influences recovery. For example, flood insurance or the receipt of government compensation payments might also play a decisive role in this context. This has not been investigated in this study, however, will be a subject of further analyses.

4.5 Lessons learned – will people be better prepared for future floods?

Finally, the question arises, whether the recent flood experience motivated people to perform (more) risk reduction measures shortly after the flood or in the near future. Therefore, respondents were asked whether they implemented any precautionary measures after the flood or whether they were planning to undertake some within the next six months. The results are shown in Fig. 9.

Private flood prevention improved after each flood event of the study subsets, especially after 2005 and 2010 (Fig. 9). After these two years, precautionary measures like the sealing of the basement/building, the purchasing of water barriers and the adaptation of furnishing/interior equipment or building use increased the most (between 56 and 113 %). After 2006, though, only the purchasing of water barriers increased by more than 50 %; and after 2011, no measure improved by more than 25 %. The lower values of the latter two study subsets might be explained by the fact that flood precaution was already at a much higher level before the respective events (see

Sect. 4.2, Fig. 2). In comparison, after 2002 almost all measures more than doubled, but started at a considerably lower level.

Between 2005 and 2011, the maximum proportion of planned measures within the next six months amounted to 6 % and was approximately in the same range as in 2002. However, about 8 % of all households interviewed decided to move to a flood safe area or at least planned it for the near future. In 2002, this share was only 3 %. This slight increase seems to be consistent with media reports, in which retreat/resettlement is felt to be mentioned more often as a risk reduction measures than ten years ago. This aspect has to be investigated in the future.

The overall results clearly show that the risk awareness of most affected households increased after the flood events of the study subsets. This led to an increased implementation of additional measures, particularly in years with a previous low precaution level. A positive development is that mainly building retrofitting and adaptation of building and furnishing use improved, as these kinds of damage reduction measures are considered particularly effective (Kreibich et al., 2005). Nevertheless, these percentages still have to be increased as the study subset of 2011 reveals that a higher level of private precaution can be achieved.

5 Conclusions and recommendations

During the flood in 2002, people's ability to cope with the flood was low, resulting in high building and contents losses. Since many governmental activities to improve flood protection, but also flood awareness and precaution have been undertaken, the question arose how residents reacted during recent flood events between 2005 and 2011. In general, this study shows that much has been achieved since 2002; however, there is still much room for further improvements. Table 11 provides a qualitative overview of all obtained results of this study.

Particularly the state of private precaution increased after the 2002 flood. Merely about 7 % of all households interviewed had not performed any precautionary measure.

Best precaution was performed before the flood events in 2011 and 2006, which might be explained by more flood experience and overall greater risk awareness of the residents. However, on average 53 % of all respondents had only undertaken information precaution or participated in networks, which is not per se leading to a damage reduction. Accordingly, investments in flood-proofing or retrofitting measures still need to be stimulated in order to reduce future damage more efficiently.

Early warning and emergency response were apparently strongly dependent on the floods characteristics and the regional topography, but were also influenced by previous flood experiences of the respondents. Therefore, a constant improvement over the years could not be observed, but rather corresponding results of flood events in 2005 and 2010 tended to be lower than those of 2006 and 2011. Hence, it is important to further improve early warning systems and communication channels, especially in hilly areas with rapid onset floods, to enable more people to respond to the threat of flooding.

Flood losses and the recovery status also seem to be influenced by the flood characteristics. The overall improved flood precaution and the larger share of people knowing how to protect themselves could counteract damages only to a certain extent. However, flood damages are most likely the result of additional influencing factors. Accordingly, more detailed studies are needed to investigate essential key factors to estimate and describe flood damages more precisely.

After the flood event, respondents became more aware of their risk exposure and were motivated to invest in flood proofing and building retrofitting measures in future. Yet, the challenge remains to increase the precaution level of private households, especially in areas with low previous flood experience and risk awareness.

The investigations of this study were primarily descriptive. For future investigations, it would therefore be interesting to focus on single key factors and to perform theory- or model-based analyses. E.g. it is known that flood experience is an important precondition for the implementation of precautionary measures. But there are studies that question the importance of the relationship between risk awareness and the adoption of private mitigation measures and assume other factors more influential (Bubeck et al., 2012a; Scolobig et al., 2012), e.g. policy changes, people's perception regarding the responsibility for flood protection, trust in public flood protection, severity of the experienced adverse flood consequences, negative emotions, coping appraisal or socio-economic and geographic variables (Grothmann and Reusswig, 2006; Siegrist and Gutscher, 2008; Botzen et al., 2009; Zaalberg et al., 2009; Kreibich et al., 2011; Terpstra, 2011). Therefore, more detailed investigations are needed to analyse what (other) factors influence people's precautionary behaviour. This could optionally be examined on the basis of the protection motivation theory introduced by Rogers (1975).

Furthermore, some aspects seem to be mainly influenced by the region, e.g. behaviour seems to be influenced by a certain "risk culture". In contrast, other variables, such as flood warning (lead time) seem to be dominantly influenced by the flood event and its flow characteristics (intensity, velocity of onset etc.). These aspects also have to be investigated in more detail in the near future. And finally, based on these results it should be investigated how flood damage models can be improved.

Appendix A:

Due to the lower number of affected households in both telephone surveys 2006 and 2012, all available phone numbers were researched and called. In the 2006 survey, these were 9964 phone numbers and 20 262 phone numbers in 2012, broken down as listed in Tables A1 and A2.

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Table 1. Hydro-meteorological conditions and financial damage of the investigated flood events.

Flood event	Aug 2002
Affected river catchments	Danube, Elbe/Labe
Preconditions and meteorological causes	High preceding soil moisture were followed by a Vb weather system with extensive rainfall in Austria, the Czech Republic, Slovakia and Germany
Damage	€11 600 million (Thieken et al., 2006)
Flood event	Aug 2005
Affected river catchments	Danube, Elbe/Labe
Preconditions and meteorological causes	Reduced snow cover formation due to mild temperatures in the Alpine region and high preceding soil moisture were followed by a Vb weather system with extensive rainfall in Austria, Switzerland and Germany
Damage	€175 million (Kron, 2009)
Flood event	Mar/Apr 2006
Affected river catchments	Elbe/Labe, Danube
Preconditions and meteorological causes	Complete snowmelt due to rapid temperature increase, accompanied by heavy rainfall from westerly cyclones
Damage	€120 million (Kron and Ellenrieder, 2008)
Flood event	Aug 2010
Affected river catchments	Elbe/Labe, Oder/Odra
Preconditions and meteorological causes	Three consecutive fronts (classical Vb-weather system track but not classical formation) with heavy rainfall; flooding was intensified by a dam breach at the Witka River
Damage	€839 million (EC, 2014)
Flood event	Jan 2011
Affected river catchments	Rhine, Danube, Elbe/Labe, Oder/Odra, Weser
Preconditions and meteorological causes	Spacious snowmelt due to rapid temperature increase and heavy rainfall followed by more intense rainfall
Damage	More than €100 million (Axer et al., 2012)

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Table 2. Chronological overview of flood events and respective surveys.

Flood event	Subsample	*n*	Period of interviews	Time lag between flood event and interviews [months]
Aug 2002	reference subset	1697	8 Apr to 10 Jun 2003	8–10
Aug 2005	study subset	305	20 Nov to 21 Dec 2006	15–16
Apr 2006	study subset	156		7–8
Aug 2010	study subset	349	16 Feb to 20 Mar 2012	18–19
Jan 2011	study subset	209		13–14

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Table 3. Numbers and shares of interviews with respect to the affected river catchment.

Catchment	Reference subset		Study subsets							
	2002		2005		2006		2010		2011	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Danube	449	26.5	276	90.5	41	26.3				
Elbe/Labe	1248	73.5	29	9.5	115	73.7	162	46.4	21	10.0
Oder/Odra							157	45.0	5	2.4
Rhine							30	8.6	183	87.6
Total	1697		305		156		349		209	

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Table 4. Items of the survey that were used in this paper.

Item	Units and labels
Socio-economic variables	
Age of the interviewee	Number of years
Education	Type of degree
Household size	Number of people
Monthly net income of the household	Euro
Living area per person	m^2
Homeowners	tenant/homeowner/owner of a flat
Flood experience *before* the flood event	
Previously experienced floods	Number of events
Time period since the last flood event	Number of years
Knowledge about the flood hazard of the residence/plot (only questioned when no previous flood had been experienced)	0: no knowledge, 1: knowledge of flood hazard
Preparedness (*before/after* the flood) and risk awareness	
Informational precaution	Type of measures and time of performance
Flood insurance	0: no insurance, 1: insurance, and time of contract conclusion
Flood-proofing measures and retrofitting	Type of measures and time of implementation
Characteristics of the inundation	
Water level	cm above top ground surface
Flood duration	Hours
Contamination of the flood water	0: no contamination, 1: sewage, 2: chemicals (and sewage), 3: oil (and chemicals or sewage)
Warning and response *before/during* the flood event	
Lead time	Hours
Perceived knowledge about self-protection	Rank from 1 (I knew exactly what to do) to 6 (I did not know what to do)
Emergency measures	Type of performed measure and perceived effectiveness of each measure evaluated on a scale from 1 (very effective) to 6 (totally ineffective)
Adverse effects of the flood events	
Damage to the building	Euro
Damage to household contents	Euro
Recovery	
Perceived status of restoration of the building/replacement of household contents at the time of the interview	Rank from 1 (buildings/household contents are already completely restored/replaced) to 6 (there is still considerable damage to the building/to household contents)

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Table 5. Description of the different flood events with respect to socio-economic variables, previously experienced floods and flood impact (figures do not refer to all interviews, but to the respective number of valid responses).

Flood event	2002	2005	2006	2010	2011	Germany
Socio-economic variables						
Mean age of the interviewees [years]	52	52	55	57	57	male: 42.8, female: 45.5 (2012)[b]
People with high school graduation/university degree (German Abitur/Fachabitur/Hochschul-/Fachhochschulabschluss) [%]	30.7	37.8	39.1	27.8	32.7	unknown
Mean household size [number of people]	2.8	2.9	2.7	2.5	2.6	2.0 (2010)[c]
Households with a monthly net income < €1500 [%]	29.9	19.0	28.2	25.5	14.4	25.9 (2008)[d]
Mean living area per person [m^2]	47.9	48.7	51.1	46.0	63.2	45.1 (2010)[e]
Homeowners [%]	75.8	76.7	83.3	84.8	89.0	46.0 (2010)[e]
Flood experience BEFORE the respective event						
People who experienced at least one previous flood [%]	21.9	55.4	82.7	52.1	77.5	
thereof: People who experienced a flood in the last ten years [%]	58.1	74.0	89.1	57.6	75.3	
People who had not experienced at least one previous flood [%]	77.8	41.6	13.5	47.0	21.5	
thereof: People with knowledge about the flood hazard of their property [%]	30.6	52.0	52.4	40.9	68.9	
Characteristics of the flood impact						
Mean flood duration [h]	143	52	146	67	104	
Mean water level above top ground surface [cm][a]	64.2	−19.4	18.8	58.3	−19.5	
Interviews that reported oil or petrol contamination [%]	38.5	13.8	13.5	15.5	6.7	

[a] assuming a basement depth of 2.50 m below top ground surface.
[b] BiB (2014a).
[c] BiB (2014b).
[d] Kott and Behrends (2011).
[e] DESTATIS (2013).

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Table 6. Answers to the question: "How did you become aware of the danger of flooding?"; given in percentage of all interviewed people per flood event (multiple answers possible) and average lead time per subsample.

Flood event	2002	2005	2006	2010	2011	Total (2005–2011)
Own observation	33.4 %	28.9 %	29.5 %	41.0 %	56.9 %	38.9 %
Flood warning by authorities	40.5 %	32.8 %	34.0 %	23.5 %	45.0 %	32.3 %
Severe weather warning by radio, TV etc.	[a]	23.6 %	41.7 %	20.1 %	42.1 %	28.9 %
Warning by neighbours, friends etc.	13.3 %	12.1 %	16.7 %	16.3 %	15.8 %	15.0 %
General reporting in nationwide news	13.9 %	8.5 %	13.5 %	5.7 %	12.0 %	9.0 %
Gauge information	[a]	[a]	[a]	0.3 %	3.3 %	1.4 %[b]
Warning and evacuation at the same time	1.2 %	[a]	[a]	[a]	[a]	
Other warning sources (sms, public services)	0.4 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
No warning	26.8 %	26.9 %	11.5 %	32.4 %	6.2 %	22.2 %
No answer	0.7 %	1.0 %	1.3 %	0.3 %	0.0 %	0.6 %
Number of valid interviews	1697	305	156	349	209	1019
Average lead time [h]	37	16	40	11	23	20
Number of valid interviews	1005	156	103	173	158	590

[a] Data were not requested.
[b] Total value results from calculations of years 2010 and 2011.

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Table 7. Information content of official flood warnings (multiple answers possible).

Flood event	2002	2005	2006	2010	2011	Total (2005–2011)
Maximal water level	33.1 %	39.2 %	59.6 %	36.4 %	67.8 %	50.0 %
Residential areas at risk	57.0 %	48.5 %	46.2 %	51.9 %	51.1 %	49.7 %
Time to peak water level	26.0 %	33.0 %	57.7 %	26.0 %	46.7 %	39.2 %
Advice for damage reduction	35.1 %	38.1 %	28.8 %	49.4 %	31.1 %	37.3 %
Information about diversions, road blockings etc.	*	9.3 %	26.9 %	26.0 %	21.1 %	19.6 %
Information about evacuation	22.6 %	20.6 %	25.0 %	28.6 %	4.4 %	18.7 %
Information about levee breaches	*	6.2 %	5.8 %	16.9 %	3.3 %	7.9 %
Other useful information snowmelt, emergency numbers	2.2	1.0 %	1.9 %	0.0 %	0.0 %	0.6 %
None of this information	10.2 %	10.3 %	15.4 %	6.5 %	4.4 %	8.5 %
Not specified/no answer	5.4 %	9.3 %	1.9 %	7.8 %	10.0 %	7.9 %
Number of valid interviews (i.e. people warned by authorities)	647	97	52	77	90	316

* Inter alia data were classified as “other useful information”.

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Table 8. Reasons why people did not perform emergency measures (multiple answers possible).

Flood event	2002	2005	2006	2010	2011	Total (2005–2011)
It was too late to do anything	61.1 %	65.2 %	33.3 %	56.1 %	35.3 %	55.9 %
Nobody was at home	18.3 %	18.2 %	25.0 %	17.5 %	11.8 %	17.8 %
I did not think the flood would become so severe	5.3 %	12.1 %	16.7 %	15.8 %	0.0 %	12.5 %
I thought emergency measures would be ineffective	8.8 %	4.5 %	16.7 %	5.3 %	11.8 %	6.6 %
I did not know what to do	3.5 %	1.5 %	0.0 %	7.0 %	5.9 %	3.9 %
I was not capable to do anything	2.8 %	1.5 %	8.3 %	0.0 %	11.8 %	2.6 %
I thought emergency measures wouldn't be necessary	8.8 %	*	*	*	*	*
Others	1.8 %	3.0 %	0.0 %	17.5 %	23,5 %	10.5 %
Flood adapted building/contents use		0.0 %	0.0 %	5.3 %	23.5 %	4.6 %
No warning		0.0 %	0.0 %	12.3 %	0.0 %	4.6 %
Recently moved in/irresponsible		3.0 %	0.0 %	0.0 %	0.0 %	1.4 %
Not specified/no answer	3.2 %	1.5 %	0.0 %	3.8 %	0.0 %	2.0 %
Number of valid interviews	284	66	12	57	17	152
Percentage of valid interviews (i.e. people performed no emergency measures)	16.7 %	21.6 %	7.7 %	16.3 %	8.1 %	14.9 %

* Data were not requested since distinction between "I did not think the flood would become so severe" or "I thought emergency measures would be ineffective" was found to be difficult.

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Table 9. Flood damage of buildings.

Flood event	Flat-rate loss							Mean direct damage reported by GDV (2013) [€]
	Excluding					Including		
	n	Mean damage [€]	Median damage [€]	Mean damage corrected by building cost index (June 2013) [€]	Median damage corrected by building cost index (June 2013) [€]	*n*	Minor damage up to €250 [%]	
2002	1079	42 093	24 000	52 681	30 037	1080	2.5	13 500
2005	158	19 302	7400	23 626	9058	160	6.2	no data
2006	85	24 814	10 000	30 191	12 167	88	6.8	no data
2010	224	43 695	20 000	46 832	21 436	228	5.3	14 000
2011	119	10 765	2000	11 369	2112	133	21.8	2100

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Table 10. Flood damage of household contents.

Flood event	Flat-rate loss							Mean direct damage reported by GDV
	Excluding					Including		
	n	Mean damage [€]	Median damage [€]	Mean damage corrected by consumer price index (June 2013) [€]	Median damage corrected by consumer price index (June 2013) [€]	*n*	Minor damage up to €250 [%]	
2002	1271	16 361	8500	19 500	10 131	1276	2.9	unknown
2005	150	13 418	5000	15 318	5708	155	13.5	unknown
2006	45	12 754	2000	14 343	2249	48	12.5	unknown
2010	222	17 884	10 000	18 886	10 560	224	3.1	unknown
2011	47	7957	2000	8230	2069	48	12.5	unknown

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Table 11. Qualitative summary of all results.

Section	Results	2002	2005	2006	2010	2011
4.2.	Preparedness level	Low	Medium	High	Medium	High
4.3.1, 4.3.2	Warning	Bad	Medium	Good	Medium	Good
4.3.3	Response	Medium	Medium	Good	Medium	Good
4.4.1	Damage	High	Medium	Medium	High	Low
4.4.2	Recovery	Slow	Slow	Medium	Slow	Fast
4.5	Post-flood precaution improvement	High	High	Medium	High	Low

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Table A1. Subdivision of the called phone numbers in the survey 2006.

	n
Answering machine	726
Busy line	136
Wrong phone number	818
Dead line	23
Dial tone	972
Refusal	2075
Appointment not within the survey period	18
Termination of the call	71
Wrong target group	343
Interviewee not affected by flood	4321
Successful interviews	461

Table A2. Subdivision of the called phone numbers in the survey 2012.

	n
Dead line	3633
Refusal	3230
Not reachable within the survey period	4403
Termination of the call	164
Interviewees not affected by flooding	8174
Successful interviews	658

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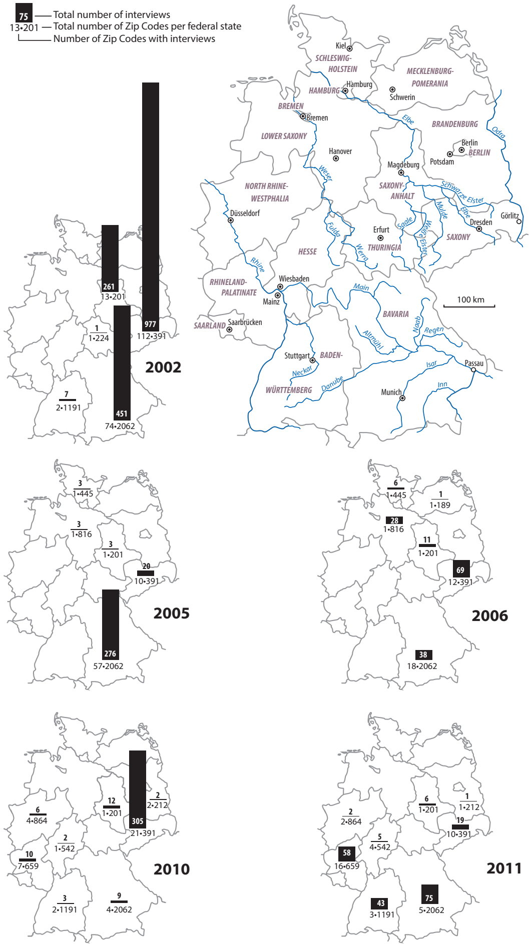
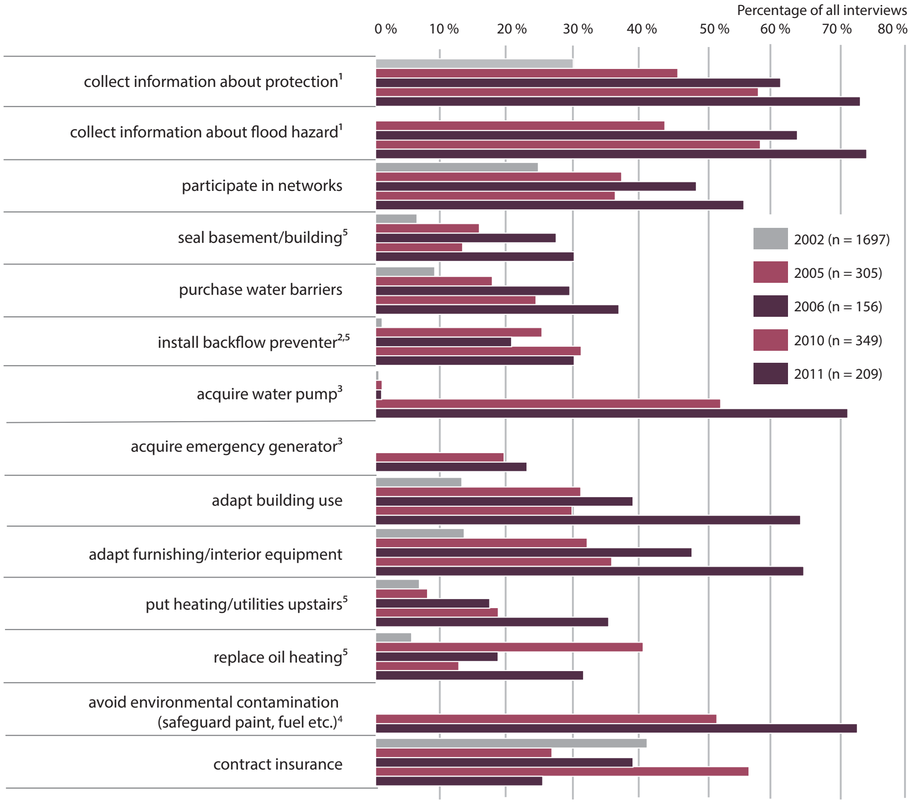


Figure 1. Federal states, where interviews of the respective subsamples were conducted.



[1] in 2002, collection of information about protection and flood hazard have not been requested individually but summarized in category "collect information about protection"

[2] measures were not explicitly requested in 2002, but deduced from open answers

[3] measures were not explicitly requested in 2002, 2005 and 2006, but deduced from open answers. Additionally, no distinction was made between acquisition of pumps and emergency generators. Measures were therefore summarized in the category "acquire water pump"

[4] measures were retrieved only from surveys 2010 and 2011

[5] measures were only given to homeowners

Figure 2. Precautionary measures performed by private households before the respective flood event.

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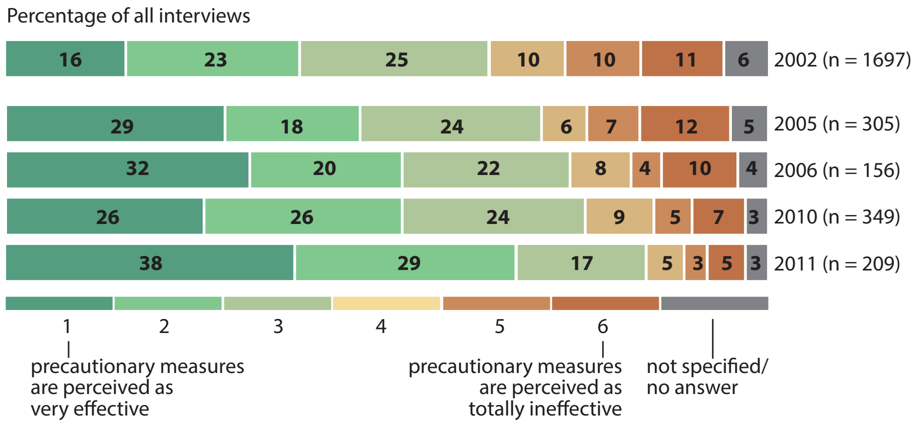

Figure 3. Perceived effectiveness of private precautionary measures.

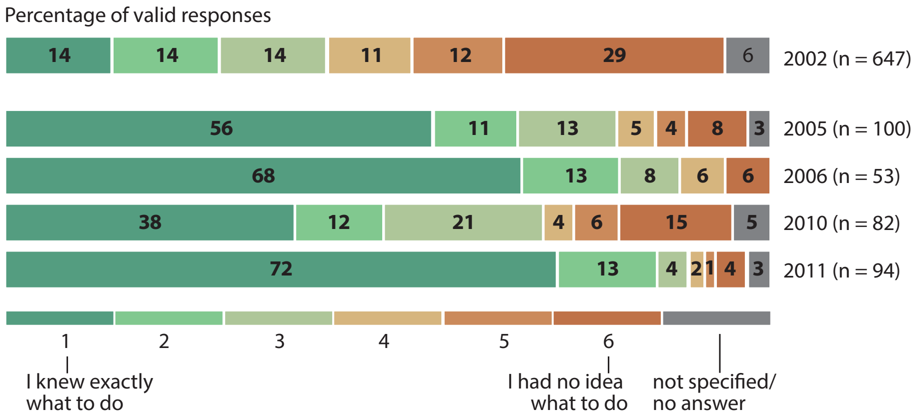

Figure 4. People's knowledge about how to protect themselves and their households against the flood.

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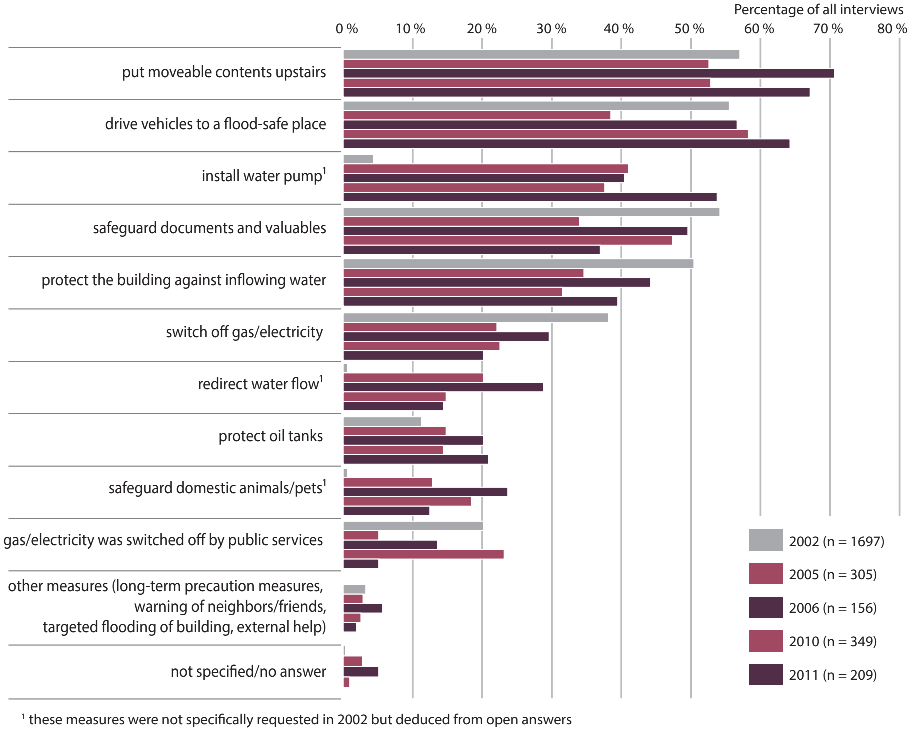

Figure 5. Emergency measures performed (in descending order), as a percentage of all interviewed people per year (multiple answers possible).

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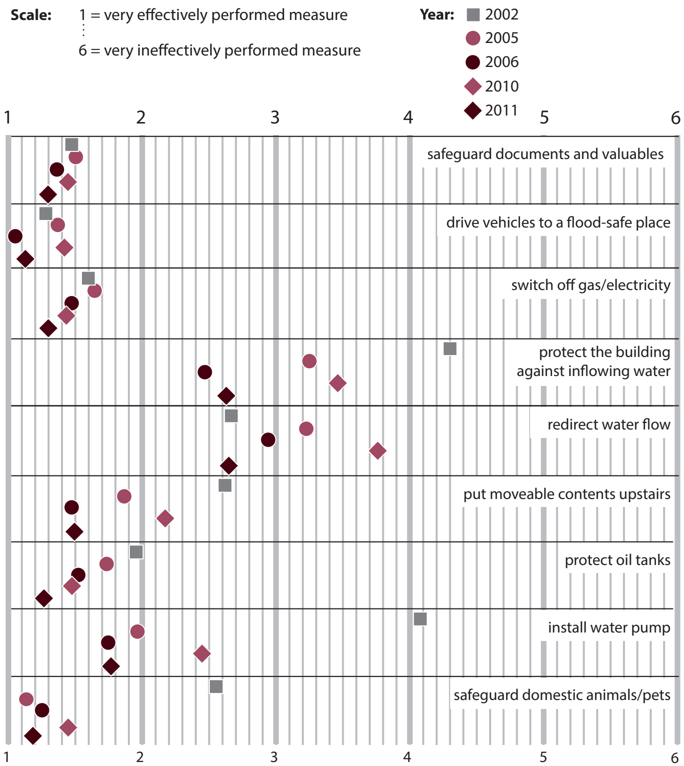

Figure 6. Average effectiveness of emergency measures as evaluated by the people interviewed on a scale from 1 (= measure was very effective) to 6 (= measure was very ineffective).

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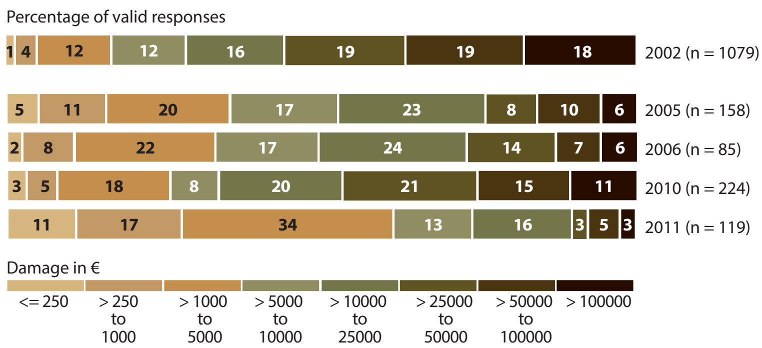

Figure 7. Classified damage to residential buildings (excluding minor damage flat-rate), prices as at June 2013.

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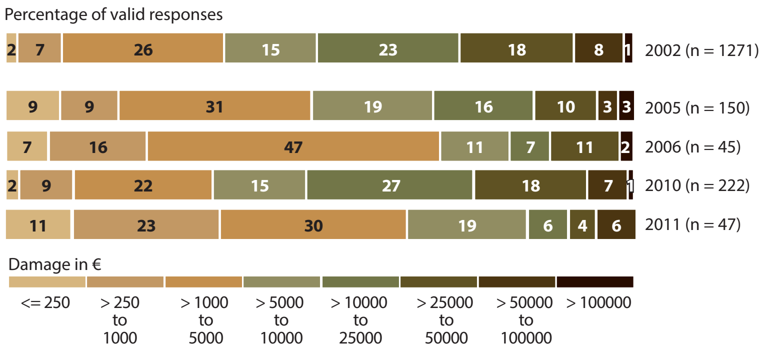

Figure 8. Classified damage to household contents (excluding minor damage flat-rate), prices as at June 2013.

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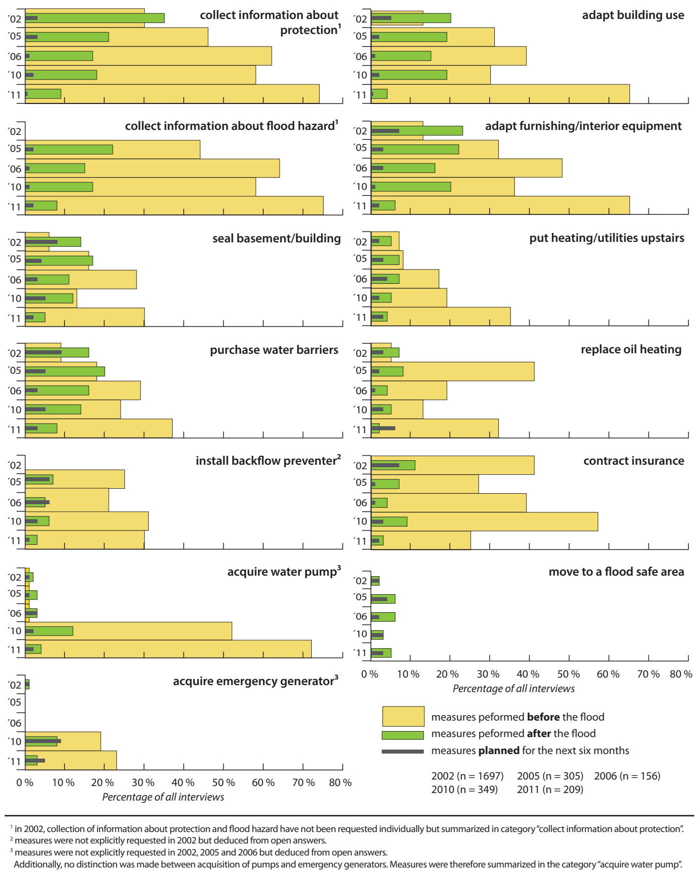

Figure 9. Precautionary measures undertaken in private households before and after the respective flood events, and measures that are planned for the next six months.