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Running head: Coping with floods in the city of Dresden, Germany

Title: **Coping with floods in the city of Dresden, Germany**

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Abstract

During August 2002 and again in March 2005 as well as in April 2006 the city of Dresden was hit by floods. The flood in 2002 was an extreme event, only comparable to flooding in 1862 and 1890 in Dresden. The flood discharge in 2006 was the second highest discharge since 1940 at the Dresden gauge although its return period was only about 15 years. This special situation enables a comparison of the preparedness of authorities and households in the flood endangered city of Dresden in 2002 after a long period of relatively low flood discharges and in 2005/2006 just a few years after a severe flood event. Before August 2002, the flood risk awareness and flood preparedness of authorities and households in Dresden was low. The inundation channels and the Elbe river bed had not been maintained well. Just 13% of the households had undertaken building precautionary measures. The severe flood situation as well as the low flood preparedness led to tremendous damage, e.g. losses to residential buildings amounted to 304 million €. After 2002, the municipal authorities in Dresden developed a new flood management concept and many households were motivated to undertake precautionary measures. 67% of the households had actually undertaken building precautionary measures before the floods in 2005 and 2006. Flood damage was significantly lower, due to the less severe flood situations and the much better preparedness. It is an important challenge for the future to keep preparedness at a high level also without recurrent flood experiences.

Key words

Dresden, Elbe, flood impact, flood damage, preparedness, precautionary measures, flood management

1. Introduction

In August 2002, heavy rainfall led to extreme floods in the Elbe and the Danube basins (DKKV, 2003; Ulbrich et al., 2003; Engel, 2004; IKSE, 2004). In Germany, 21 people were killed and substantial parts of the infrastructure were destroyed. The estimated costs amounted to 11.6 billion € for Germany alone (Thieken et al., 2006). Located on the Elbe River (Fig. 1), Dresden was the most affected area in Germany with losses to residential buildings of 304 million € (Kreibich et al., 2005a). Being the state capital of the federal state of Saxony, the city has numerous cultural and historic sites and has experienced important developments in industry and research throughout the centuries since its foundation at the beginning of the 13th century. Dresden has 478 000 inhabitants living in 255 000 households (Statistikamt Dresden, 2004; infas GEOdaten, 2004). Its total land area amounts to 328 km² of which the settlement area covers 38% (Fig. 1).

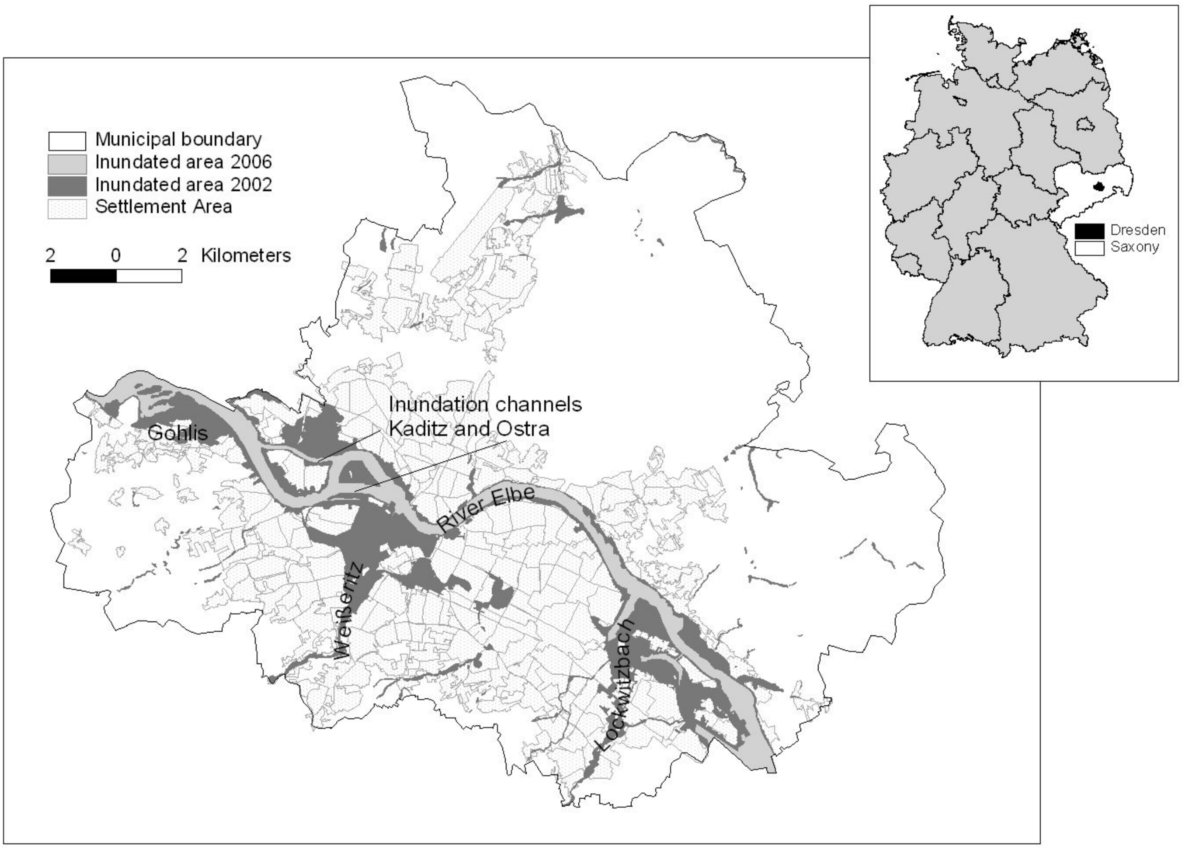

Fig. 1 Location of Dresden in Saxony, Germany. Inundated areas during the floods in 2002 and 2006. (Data sources: infas GEOdaten (2004): municipal boundary; ©Bundesamt für Kartographie und Geodäsie (2003, 2004): Inundated area in 2002, ATKIS® Basis DLM; Sächsisches Landesamt für Umwelt und Geologie & Landeshauptstadt Dresden/Umweltamt (2003): Inundated area in 2002; ZKI (2006): Inundated area in 2006).

In August 2002, Dresden was hit by floods of the River Elbe and its tributaries Weißeritz and Lockwitzbach, which discharge into the River Elbe within the city area of Dresden (Fig. 1). The flood of the Weißeritz, with a discharge of 430 $m^3 s^{-1}$, had a return period of 400 to 500 years (Umweltamt Dresden, personal communication). On 17 August 2002, the Elbe River rose up to a level of 9.40 m at the Dresden gauge (BfG, 2002).

The winters of 2004/2005 and 2005/2006 were exceptionally rich in snow. In such situations, there is a potential for flooding in the following spring time, if the thaw period is accompanied by high rainfall (Grünewald, 2006). In 2005, such a warm, rainy period occurred only for two days in March, leading to a short steep increase of the River Elbe to a maximum of 5.95 m at the Dresden gauge (Korndörfer et al., 2006). However, extensive flooding occurred only in 2006. In March 2006, in the upper Elbe catchment in the Czech Republic, the amount of water stored as snow was about 2.4 billion m^3 which was about 20% more than in 2005 (Korndörfer et al., 2006). End of March, temperatures rose rapidly to 5 - 15°C leading to a complete snowmelt within one week also in the upper parts of the middle hills (BfG, 2006). Due to several westerly cyclones snowmelt was accompanied by heavy rainfall in the whole catchment area upstream of Dresden and led to a significant increase in the water levels in the Vltava- and Elbe-catchments. At the Dresden gauge, the water level of the Elbe rose to a maximum of 7.49 m (Korndörfer et al., 2006).

In the case of floods occurring in the same region just a few years after another, this significantly influences the flood experience of the authorities and the affected population. In regions where no significant flood had occurred for decades, which was the case at the River Elbe during the second half of the 20^{th} century, flood experience and preparedness is low (Kreibich et al, 2005b; Thieken et al., 2007). Flood experience is strongly linked to preparedness, e.g. for households to undertake private precautionary measures (Kreibich et al., 2005b; Thieken et al., 2007). Homeowners who have been flooded recently are more aware of the flood risk, are interested in mitigation and willing to invest in precautionary measures (e.g. Laska, 1986; Brilly and Polic, 2005; Grothmann and Reusswig, 2006). People only act if they are aware of the flood risk and if they are informed about the possibility, effectiveness and cost of precautionary measures (Grothmann and Reusswig, 2006). Generally, preparedness consists of preventive, precautionary and preparative measures. Prevention aims to avoid damage primarily by an appropriate land-use or structural measures, preparation tries to manage and cope with the catastrophe and precaution wants to mitigate damage mainly due to private flood proofing. Private risk reduction measures may be building precautionary measures or preparative measures like collecting information about flood precaution, participating in neighbourly help or sign flood insurance. Private precautionary measures are able to significantly reduce flood damage (Wind et al., 1999; ICPR, 2002; Kreibich et al., 2005b). However, combined structural and non-structural flood mitigation seem most promising and are expected to result in significant economic benefit (Hayes, 2004). A case study undertaken by Smith (1981) revealed that in 1974 the city of Lismore in Australia was able to reduce its actual damage in the residential sector to 52.4% of the potential damage, since the community was well prepared due to frequent flooding and sufficient warning time. Even in cases like the Meuse floods in 1993 and 1995, where the severity of the second flood was comparable to that of the first one, the resulting damage of the second flood was significantly lower (Wind et al., 1999).

The purpose of the paper is to compare the preparedness of authorities and households in the flood endangered city of Dresden in 2002 after a long period of relatively low floods and in

2005/2006 just a few years after a severe flood event. Flood impacts and damage of the floods are analysed and conclusions for flood risk management are drawn.

2. Data and methods

In order to assess the recent flood events in Dresden from a hydrological point of view an annual maximum series (AMS) was derived from mean daily discharges at the Dresden gauge that are available from January 1852 to December 2006 (data sources: GRDC, Koblenz, WSA Dresden). It was presumed that the assumptions on which flood frequency analysis are built, especially stationarity, are valid since a two-sided Mann-Kendall-trend test on a significance level of 0.05 revealed no trend in the AMS (see e.g. Kundzewicz and Robson, 2004, for methodological aspects). The annual maximum discharge was determined for each hydrological year, i.e. from 1st November to 31st October. Different distribution functions were adapted to the AMS: Generalised Extreme Value distribution (GEV), Gumbel distribution (G), Pearson type III (PE3), the two- and three-parametric lognormal distribution (LN2, LN3) and the Generalised Logistic (GL). The parameters of the two-parametric functions (G, LN2) were estimated by the method of moments (MM), those of the three-parametric functions by L-Moments (LM).

To gain a comprehensive view of the flood management situation in the city of Dresden, a literature review as well as personal interviews were undertaken with experts from the authorities of different administrative levels (Petrow et al., 2006). After the flood in 2002 we interviewed experts from environmental agencies and the Urban Planning Agency of Dresden. Additionally, telephone interviews with private households in the Elbe and Danube catchments were undertaken after the flood in 2002 (Kreibich et al., 2005b; Thieken et al., 2005) and again after the floods in 2005 and 2006. Lists of all affected streets were comprised with the help of satellite and official data and building specific random samples of households were generated. Computer-aided telephone interviews were undertaken with the VOXCO software package (http://www.voxco.com) by the SOKO institute for social research and communication (http://www.soko-institut.de) in April and May 2003 and by the Explorare institute for marketing research (http://www.explorare.de) in November and December 2006. Always the person with the best knowledge about the flood damage was interviewed. The survey about the 2002 flood resulted in 1697 interviews including 300 completed interviews in Dresden. The second poll concerning flooding in 2005 and 2006 contained 461 interviews with 21 completed interviews in Dresden. Due to the relatively small number of interviews in Dresden from the second poll, we don't distinguish between the households affected by the flood in 2005 (n = 7) or by the flood in 2006 (n = 14).

Both questionnaires addressed the following topics: precautionary measures, flood experience, flood parameters (e.g. contamination, water level), socio-economic parameters and flood damage. More details about the survey and the data processing after the flood in 2002 are published by Kreibich et al. (2005b) and Thieken et al. (2005, 2007). A flow velocity indicator was developed based on information about deposited material, water levels, two qualitative velocity assessments, flood types, damage to the building fabric and the way the water intruded the building (see Thieken et al., 2005). The indicator contains the values: 0 = stagnant/very low, 1 = moderate, 2 = high, 3 = very high flow velocity. Further, an indicator for the contamination of the flood water was introduced, with values from 0 = no, 1 = medium and 2 = high contamination (i.e. multiple contamination including oil or petrol). The indicator for precaution takes into account how many and what precautionary measures were undertaken before the flooding and ranges from 0 = no building precaution to 2 = very good precaution (two or more building precautionary measures and others undertaken). Building precautionary measures were for instance elevated configuration, shielding with water barriers, waterproof sealing, fortification, flood adapted use, flood adapted interior fitting. Significant differences between two independent groups of data were tested by the Mann-Whitney-U-Test (Norušis, 2002).

3. Results and discussion

3.1 Assessment of the floods severity

On 17 August 2002, the Elbe River rose up to a level of 9.40 m at the Dresden gauge (BfG 2002). Although this water level had never been reached in Dresden before – the highest water level of 8.77 m had been observed in 1845 - the return period of this event was estimated to be around 150 years only (e.g. Umweltatlas, 2002). Measurements revealed that the peak discharge in 2002 was 4580 m^3s^{-1} and therefore considerably lower than in 1845, for which a reconstructed discharge of 5700 m^3s^{-1} has been assumed (Grünewald, 2006). As shown in Fig. 2, the discharge of the flood in 2002 is comparable to flooding in 1862 and 1890. Although considerably lower than in 2002, the flood discharge in 2006 was the second highest discharge since 1940 at the Dresden gauge (Fig. 2). As can be seen from the annual maximum series, no discharge exceeded a value of 2500 $m^3 s^{-1}$ in the second half of the 20th century (Fig. 2).

In order to compare the three flood events under study, the official data series of the mean daily discharge between 1852 and 2006 was used for a flood frequency analysis. Different distribution functions were adapted to the AMS (Fig. 3) and were used to estimate the return periods of the floods in 2002, 2005 and 2006. With this approach the mean return period of the flood event in 2002 amounts to around 125 years, whereas the return periods of the flood events in 2005 and 2006 are considerably lower with 3 and approximately 15 years, respectively (Table 1). Table 1 also reveals that the estimation of the return period of extreme flood events is uncertain depending on the method applied. Thus, the estimation of the return period of the 2002 event is still a subject of discussion. New estimates, which take into account historical changes of the river bed, assess the 2002 flood as a 1000-year event and assume that the measured discharge of 4580 m^3s^{-1} is the highest value ever occurred at Dresden (Pohl, 2007). This underlines the severity of the flood in 2002.

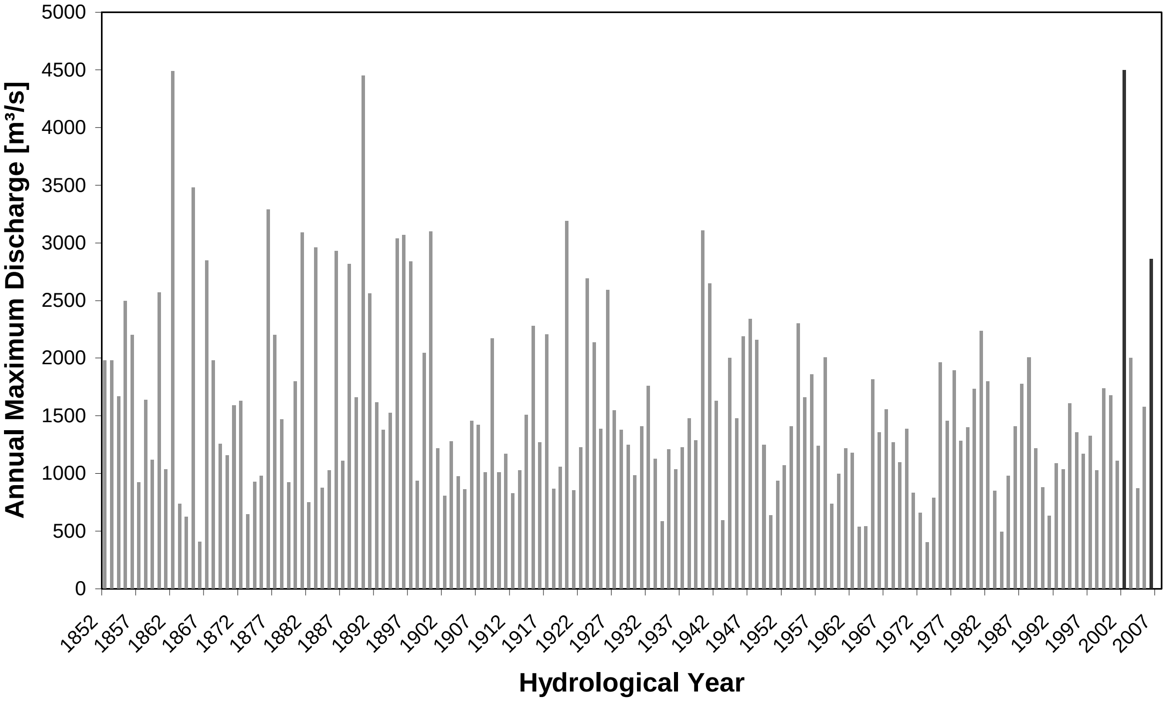

Fig. 2 Annual Maximum Series 1852-2006 at the Dresden gauge (data sources: GRDC Koblenz, WSA Dresden). The flood discharges in 2002 and 2006 are highlighted in black. The mean flood discharge of the AMS amounts to 1591 m³s^{-1}.

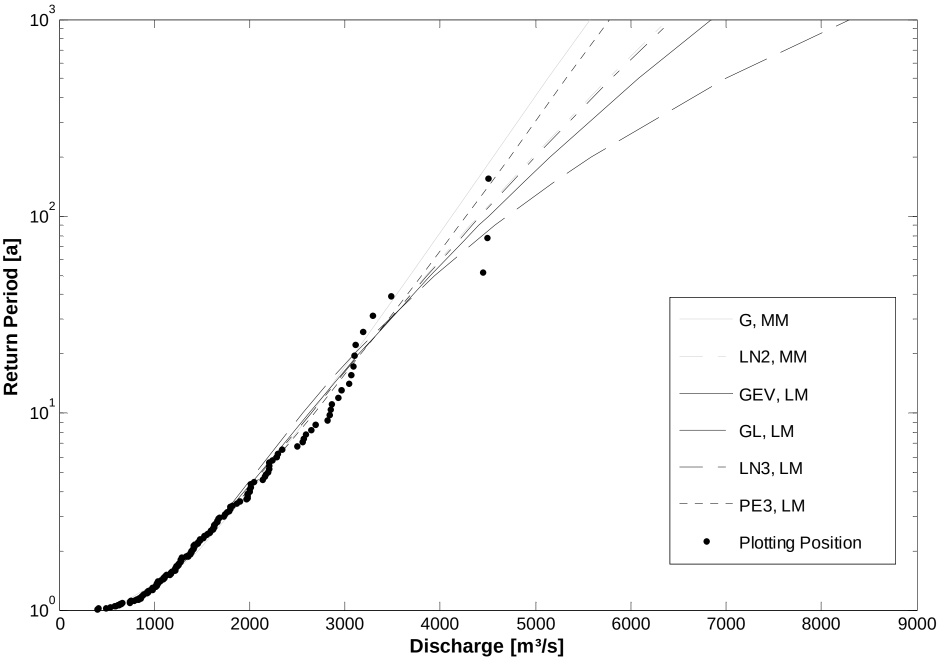

Fig. 3 Flood frequency analysis at the Dresden gauge based on the annual maximum series 1852-2006 (abbreviations: G: Gumbel, LN2: 2-parametric lognormal, GEV: generalised

extreme value, GL: generalised logistic, LN3: 3-parametric lognormal, PE3: Pearson type III, MM: method of moments, LM: L-Moments).

Table 1 Estimated return periods of recent flood events in Dresden on the basis of the annual maximum discharge series 1852-2006 (for abbreviations see Fig. 3).

	Distribution function						
Flood event	G, MM	LN2, MM	GEV, LM	GL, LM	LN3, LM	PE3, LM	Mean
August 2002	185	115	100	85	112	143	123
March 2005	3	3	3	3	3	3	3
April 2006	14	14	14	15	14	13	14

The flood in 2002 inundated about 25% of the settlement area in Dresden, i.e. 31.10 km^2 (Fig. 1). In 2006 only 1% of the settlement area in Dresden, i.e. 1.61 km^2 was flooded. For the 2005 flood, no information is available about the inundated area. In 2002, 35 000 people had to be evacuated (DKKV, 2003). In 2006, only the quarter Gohlis, where the levees were due to be overtopped, had to be evacuated (Körndörfer et al., 2006).

3.2 Flood management by authorities

The city of Dresden has a long history of floods and flood management. The oldest documented extreme flood occurred in 1501. In 1845, the city was hit by a very severe flood with a water level of 8.77 m and an estimated discharge of 5700 m^3 s^{-1} (see above). As a consequence, a variety of preventive measures with an emphasis on appropriate land use were established. Huge flood plains along the river in the city area of Dresden were kept free of settlements for many years. After severe flood events in 1845 and 1890, two inundation channels were built in Dresden between 1906 and 1910 and between 1918 and 1921, in order to effectively conduct water through the inner city of Dresden during flood situations (Korndörfer, 2003; Pohl, 2007; see Fig. 1). Altogether, flood management in Dresden relies more on retention areas than on technical flood protection. Before 2002, the last flood events that caused damage in Dresden occurred in the 1940s (Fig. 2). Therefore, flood experience had faded and the awareness of the flood risk became low among the authorities and the local population (Kreibich et al., 2005a).

Flood plains haven't been kept strictly free and specifically in the last decades of the 20th century, settlements have been established on the flood plains and in the inundation channels, which interfere with their functionality (DKKV, 2003). Moreover, low maintenance of the river bed, which led to large alluvial deposits and vegetation growth, increased even more the water levels (DKKV, 2003). Dresden faced a huge interest in investments along the Elbe River after the reunification of Germany (Korndörfer, 2003). In the 1990s, the city established industrial areas within the flood plains, which were severely damaged in August 2002. Due to a lack of living space and a low home ownership rate, there was an enormous pressure on the authorities to establish development areas, also within the flood plains despite concerns of the environment agency (Stadtplanungsamt Dresden, 2003; Umweltamt Dresden, 2003). The status of the Elbe flood plains as landscape conservation areas was not sufficient to prevent development before 2002 (Stadtplanungsamt Dresden, 2003). In the German administrative system, the municipal authorities play the key role in appropriate land use planning because they assign a specific land use to a land parcel (Petrow et al., 2006). However, since municipalities are also dependent on the local taxes they charge, there is often a conflict between flood preventive measures and the economic development on available open land in the flood plain.

Many initiatives were launched in the aftermath of the severe flood in August 2002 in order to be better prepared in the future. Examples are the state-wide development of flood hazard maps for different scenarios: 20-year flood, 100-year flood and a more extreme event (LfUG, personal communication) and flood management concepts for 47 catchments in Saxony. Also the municipal authorities in Dresden developed a new flood management concept, which incorporates several safety levels: A minimum flood safety level of 9.24 m is now required for parts of the city along the River Elbe and for the downtown area. For the remaining areas of the city, the flood management concept differentiates according to the relevance and damage potential of the specific area. Very important spots such as historic sites will be protected up to a water level of 10 m, whereas agricultural land will only be protected against a flood of 7 m (Umweltamt Dresden, personal communication). The measures are organised in three stages: 1) Establishment of additional flood-retention space upstream of settlement areas. 2) Extension and upgrading of stream profiles in the urban area. 3) Installation of sediment catches before the streams enter developed areas (Korndörfer et al., 2006). Additionally, detailed flood defence plans were developed for floods with water levels above 7 m at the Dresden gauge. Specific measures were, for example, that six allotments were relocated in order to extend the floodable land along the banks of the Elbe (UBA, 2003). Vegetation and sedimentation along the River Elbe were removed (Umweltamt Dresden, personal communication). The conveyance of the inundation channels was re-established, e.g. two old railway bridges over the channels were removed and one bridge was newly built in a flood adapted way (Korndörfer et al., 2006). The former sports stadium, which was built on the flood plain will be removed beginning of 2008 (Umweltamt Dresden, personal communication). As a consequence of the unusually high groundwater level during the flood in 2002, the authorities initiated two measures: 1) The old town will be protected by a well gallery, i.e. groundwater wells which are able to reduce dangerously high groundwater levels via pumping are arranged around the historic city centre. 2) A groundwater monitoring programme with a warning system will be installed for the whole city (Umweltamt Dresden, personal communication). Damage mitigation via the second measure relies on the preparedness of the people. That means, that cellars have to be used in a flood adapted way, e.g. it should not be an option to use the cellar as living room, office or sauna. Additionally, people have to be prepared to clear their cellars of valuables and maybe even artificially flood their cellars in time to create the necessary counter pressure. Furthermore, building permission within the inner city shall only be issued if the groundwater regime will not be altered.

In March 2006, the environmental and the fire and disaster control agencies of the city of Dresden were on alert and prepared for a 10- to 20-years flood event. Outlets, rakes and sediment catches have been cleared constantly to support an unobstructed stream-flow (Korndörfer et al., 2006). The Kaditz inundation channel was working well in contrast to the Ostra inundation channel. Water should flow through the Ostra inundation channel from a water level of 6.20 m onwards, but it flowed through the channel delayed just when the River Elbe reached the water level of 7.20 m at the Dresden gauge (Korndörfer et al., 2006). The polder in Gohlis has functioned as planned, however, some stretches of the levee and the drainage facilities have to be improved for future use. The combination of the different measures was able to reduce the maximum water level and thus the damage significantly (Korndörfer et al., 2006). The realised and the planned preventive measures in Dresden have been thoroughly evaluated after the flood in 2006 (Umweltamt Dresden, personal communication). The process of improving the flood management in Dresden is still ongoing.

3.3 Risk awareness and private precaution

The private households in Dresden had a low risk awareness and were not well prepared in August 2002, which was similar to the situation in the whole Elbe catchment (Kreibich et al., 2005b). Only 3% of the households in the flooded areas in Dresden had flood experience before August 2002 and the last experienced flood was on average 28 years ago (Table 2). Additionally, only 23% of the flood affected households knew that their building is located in a flood prone area. The situation was significantly different in 2005/2006: In this dataset 80% of the interviewed households had flood experience which was on average 3 years ago. Most of the remaining households without flood experience knew that their building is located in a flood prone area (75%). The fraction of interviewed people who think that private precautionary measures can reduce damage effectively had increased from 65% to 90% (Table 2).

Table 2 State of flood risk awareness in 2002 and in 2005/2006 in Dresden (households interviewed after 2002 n = 300, households interviewed after 2005/2006 n = 21). All shown parameters are significantly different on a 0.05-level between the two flood periods.

	2002	2005/2006
Percentage of households with flood-experience	3%	80%
Average time since last experienced flood [years]	28	3
Percentage of households without flood experience who knew that they are living in a flood prone area	23%	75%
Percentage of households who are convinced of the effectiveness of private precautionary measures	65%	90%

Consequently, preparedness was low in 2002: Just 9% of the households in Dresden had adapted the usage and just 6% the furnishing of their house to the flood danger; only 5% had installed their heating and other utilities in higher storeys, 5% had water barriers available and 5% had a flood adapted building structure, e.g. had a specially stable building foundation, or waterproof sealed cellar walls (Fig. 4). More households had collected information about flood precaution and had participated in neighbourly help or flood networks, their proportion was 19% and 23% respectively (Fig. 4). 43% of the households in Dresden were insured against flood losses, which is for historical reasons considerably higher than the German average (Thieken et al., 2006).

The flood in 2002 motivated many households to implement risk reduction measures to be better prepared for the next flood. The percentage of households which collected information about private flood precaution and joined neighbourly help or flood networks rose to 62% and 63%, respectively (Fig. 4). Importantly, many households undertook building precautionary measures, which are especially able to reduce flood losses (Kreibich et al., 2005b). After 2002, 40% of the households in Dresden had flood adapted usage and 38% adapted furnishing in their house; 14% had installed their heating and other utilities in higher storeys and 27%

had a flood adapted building structure. Relatively few households (16%) did purchase water barriers after August 2002, although this is a relatively inexpensive and easy measure (Environmental Agency, 2003; FEMA, 1998). However, during the extreme flood event in 2002 in the whole Elbe catchment, many of the erected water barriers were overtopped and thus had no or only little effect (Kreibich et al. 2005b). The private water barriers had no significant effect on the contents damage, for buildings the mean damage ratio was reduced by 29% (Table 5). In Dresden, 25% of the households had water barriers available before 2005/2006 (Fig. 4) and these might have been more effective during these smaller floods in comparison with the 2002 flood. Anyhow, 25% of the people purchased water barriers after the 2005/2006 floods (Fig. 4). The general rise in preparedness that was observed after the flood in 2002 (including measures that were planned for the consecutive six months) was confirmed by the second survey in 2006 although different households had been interviewed. However, less households had participated in neighbourly help or flood networks before 2005/2006 (43%) than after 2002 (63%), indicating that this was a quite temporary measure for many households. In contrast, the fraction of households which had installed their heating and other utilities in higher storeys rose from 14% after 2002 to 25% before 2005/2006. The preparedness of households improved even further after the floods in 2005/2006. The percentage of households which had undertaken one of the five investigated building precautionary measures rose to 38-76% (Fig. 4). The least popular measure which has been undertaken by only 38% is the adaptation of the building structure, which is quite complex and expensive (MURL, 2000). The most popular measure was the adaptation of the furnishing (76%). Even more households collected information about private flood precaution (91%). The fraction of households participating in neighbourly help or flood networks rose to a similar level (62%) like after 2002, indicating that (only) this share of affected households can be activated to participate during and right after floods. The percentage of households with flood insurance did not increase after the floods in 2005/2006 which is most likely due to the fact that the affected households are not able to get insurance. After the 2002 flood, insurers intensified their risk assessments, e.g. an insurance application is normally only allowed if no previous damage has occurred in the past 10 years (Thieken et al. 2006). Generally, after 2005/2006, all measures, except for a flood adapted building structure, have been undertaken by the majority of households (≥ 50%) (Fig. 4).

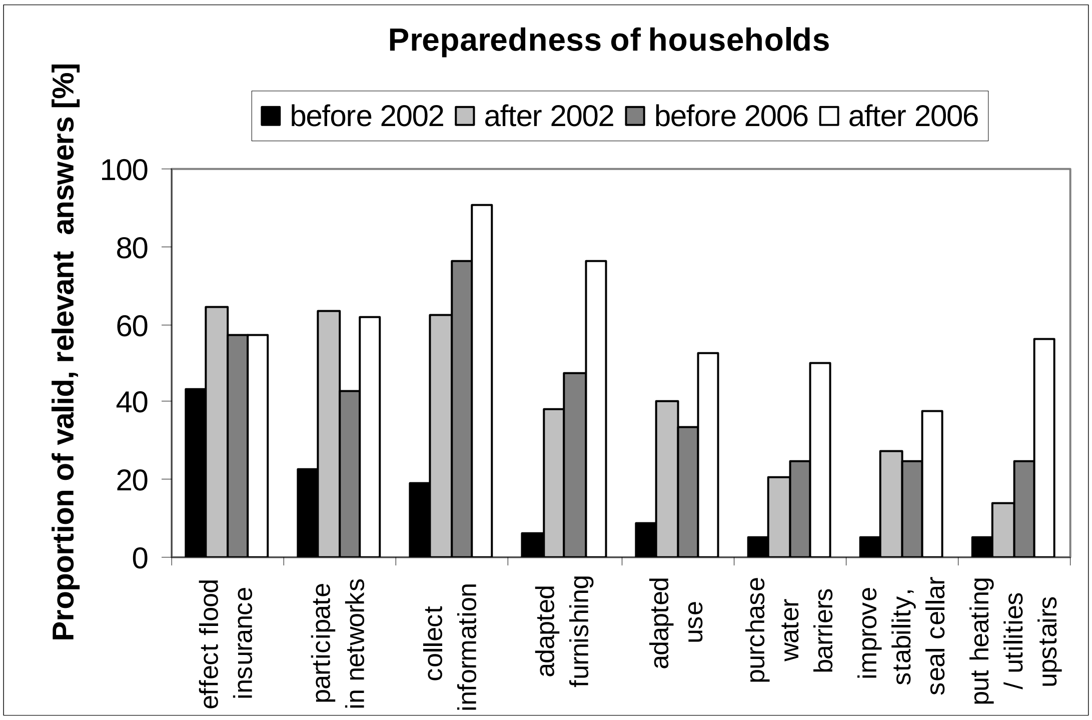

Fig. 4 Proportion of households in Dresden who had undertaken measures of precaution before and after the flood in 2002 (depending on the measure: n = 138–295) and before and after the flood in 2005/2006 (depending on the measure: n = 17-20). Only building owners were asked about improvements to the building structure, e.g. stable building foundation, or waterproof sealed cellar and the location of their heating and utilities.

3.4 Flood impact and damage

The direct flood impact on the interviewed residential buildings and contents was characterised by water level, flood duration, flow velocity and contamination indicators.

Although the mean and median water level was lower for the interviewed households affected in 2005/2006 in comparison with 2002, the reported flood impacts were significantly different for the contamination indicator only (Table 3).

Table 3 Descriptive statistics (number of cases (n), 25%-, 75%-percentile, median, mean) of the flood impact factors water level, flood duration, flow velocity indicator and contamination indicator for the 2002 and 2005/2006 floods in Dresden.

	2002				2005/2006			
	n	25%-perc.	median (mean)	75%-perc.	N	25%-perc.	median (mean)	75%-perc.
Water level [cm]*	296	0	76 (82)	163	18	-175	5 (38)	181
Flood duration [h]	294	72	120 (183)	192	20	54	144 (158)	168
Flow velocity indicator	298	moderate	moderate (1.1)	moderate	21	Very low	moderate (0.9)	moderate
Contamination indicator	292	no	medium (0.7)	medium	20	no	no (0.3)	medium

* negative values indicate a water level below ground surface, affecting only the cellar

The absolute losses to buildings and contents are correlated with the impact factors as well as with the indicator for precaution (Table 4). The main factor influencing the building and contents losses significantly is the water level, followed by the contamination indicator. Building losses are also significantly influenced by flow velocity. More information on factors influencing flood losses are published by e.g. Penning-Rowsell and Green (2000); Kelman and Spence (2004), Penning-Rowsell et al. (2005), Thieken et al. (2005) and Johnson et al. (2007). Median total building and contents losses were lower during the 2005/2006 floods in comparison with the 2002 flood, although only the contents losses were significantly lower (Fig. 5). These lower losses are due to the lower flood impact and also due to the improved state of precaution (Table 4): The indicator for precaution shows negative correlations with the building and contents losses and is significant for the building losses. The comparison of the building and contents losses of households with or without undertaken precautionary measures shows that much damage can be avoided by the means of private precautionary measures (Fig. 6). In Dresden, households which were affected by a similar flood impact achieved a significant reduction of building and contents losses (Fig. 6 B1,B2). A significant reduction due to undertaken private precautionary measures could be confirmed with the larger sample of all interviewed households in Dresden irrespective of water level or contamination (Fig. 6 A1, A2) and is in accordance with an investigation in the whole Elbe catchment (Kreibich et al., 2005b). That investigation of single precautionary measures revealed flood adapted use and furnishing as the most effective measures during the extreme flood in August 2002 (Kreibich et al., 2005b). They reduced the damage ratio for buildings by 46% and 53%, respectively. The damage ratio for contents was reduced by 48% due to flood adapted use and by 53% due to flood adapted furnishing (Table 5).

Table 4 Correlations between impact factors, precautionary indicator and resulting building and contents losses for the households affected by the 2002, 2005 and 2006 floods in Dresden (n = 133-250 depending on parameter and loss type): Sperman-Rho (pair-wise data exclusion; **correlation is significant on a 0.01-level; *correlation is significant on a 0.05-level)

	building loss [EURO]	contents loss [EURO]
Water level [cm]	0.51**	0.43**
Flood duration [h]	0.14	0.11
Flow velocity indicator	0.36**	0.01
Contamination indicator	0.23**	0.21**
Indicator for precaution	-0.18*	-0.11

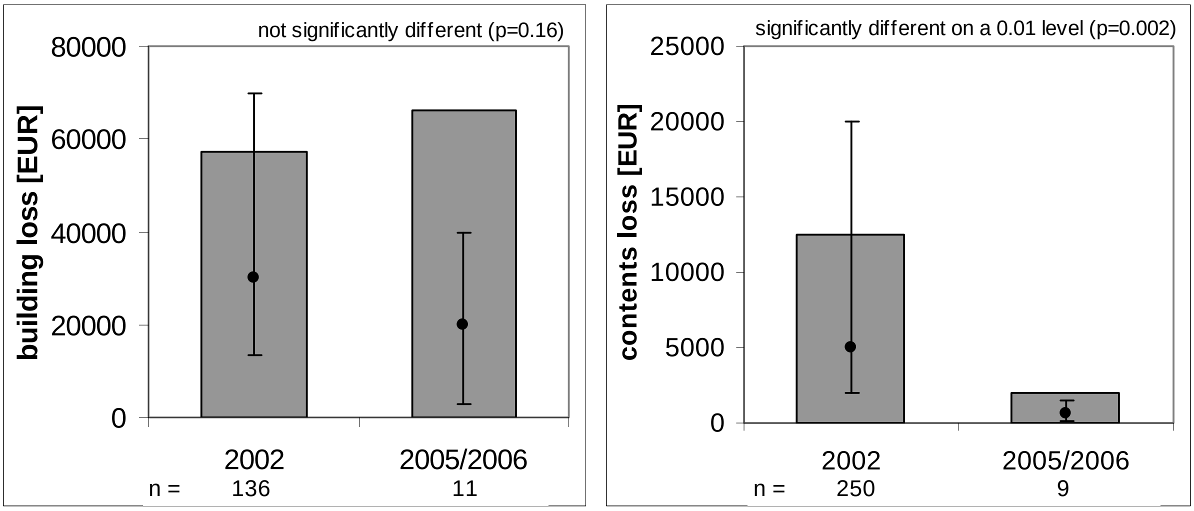

Fig. 5 Building and contents losses in 2002 and 2005/2006 in Dresden (bars = means, points = medians and 25–75 %-percentiles).

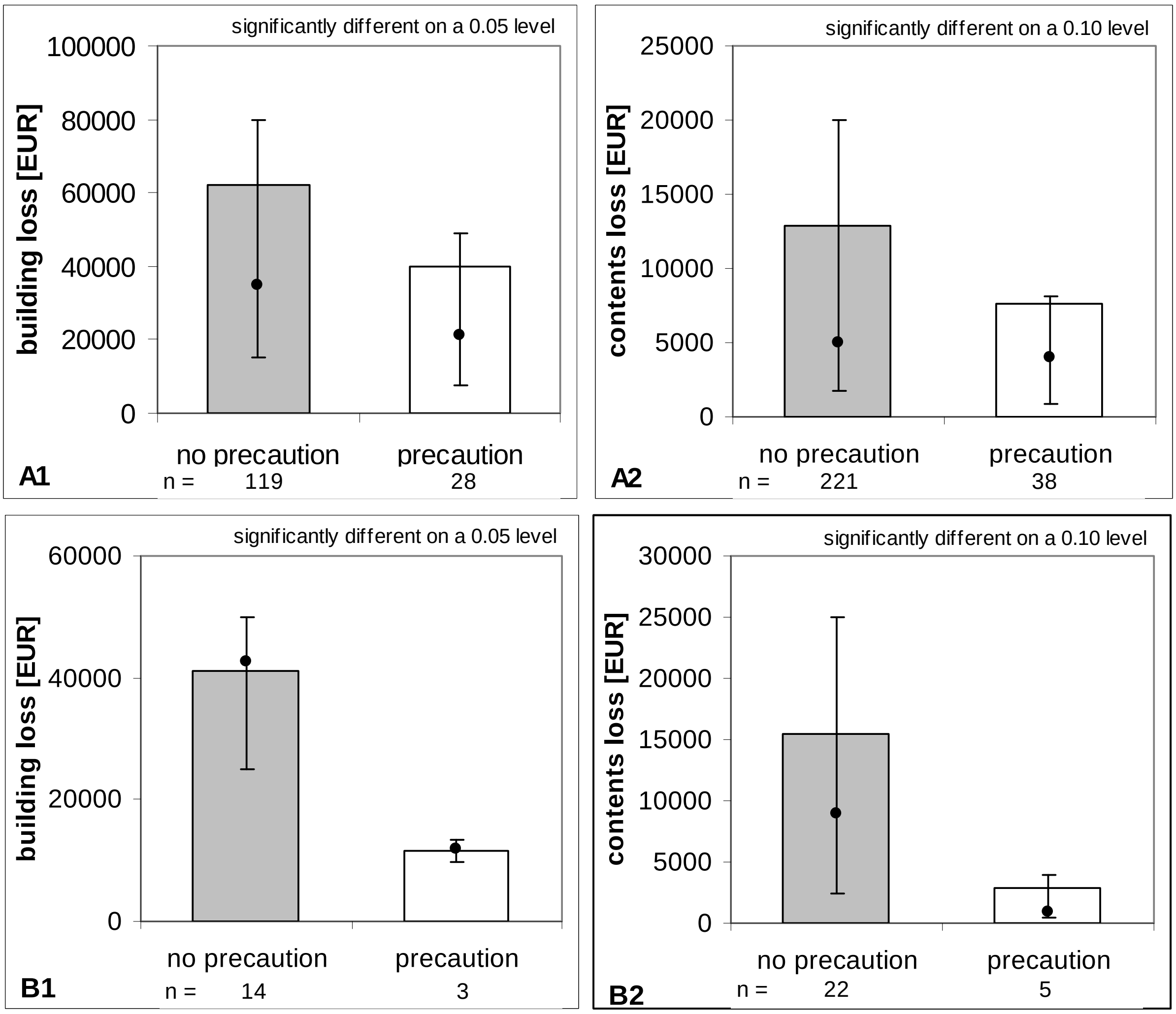

Fig. 6 Absolute building and contents losses of households with and without undertaken precautionary measures in 2002 and 2005/2006 in Dresden. Above, all cases in Dresden are taken into consideration (A1, A2), below only cases with water levels between 60-150 cm and no contamination are taken into consideration (bars = means, points = medians and 25–75 %-percentiles).

Table 5 Building and contents loss ratios [%] of households with and without private precautionary measures undertaken before the August 2002 flood in the Elbe catchment (number of cases (n), 25%-, 75%-percentile, median, mean; source: modified after Kreibich et al. 2005b).

	building loss ratios [%]								
		without measure undertaken				with measure undertaken			
	mean reduction [%]	n	25%-perc.	median (mean)	75%-perc.	n	25%-perc.	median (mean)	75%-perc.
private water barriers available	29*	605	4	11 (16)	23	54	2	7 (11)	16
flood adapted building structure	24*	572	4	11 (16)	23	37	1	5 (12)	21
flood adapted use	46*	580	4	12 (17)	23	78	1	3 (9)	11
flood adapted interior fitting	53*	589	4	12 (17)	24	67	1	3 (8)	10
installation of heating etc. in higher storeys	36*	560	4	11 (16)	23	53	2	7 (10)	15
	contents loss ratios [%]								
private water barriers available	---	883	5	15 (26)	40	63	6	17 (28)	45
flood adapted building structure	1	631	8	22 (31)	47	31	3	28 (31)	50
flood adapted use	48*	861	6	17 (27)	42	101	2	6 (14)	18
flood adapted interior fitting	53*	859	6	17 (28)	42	93	2	5 (13)	15

* loss ratios are significantly different on a 0.05 level between the households with and without the undertaken measure

CONCLUSIONS

Authorities and households in Dresden were badly prepared for the extreme flood in August 2002. Despite a long history of floods and flood management risk awareness had faded after a long period of low flood discharges and political changes. However, flood risk management and private flood precaution improved considerably after the flood in 2002. Losses during the floods in 2005/2006 were low due to the lower flood impact and the improved state of precaution. This case study exemplifies the negative consequences of faded risk awareness on the one hand and the improvements in flood preparedness right after a flood event on the other hand. To keep the awareness over time, it is recommended to make better use of the past flood experience. For example, it seems to be helpful to install or extend historical flood marks right after an event, to implement flood commemoration days, to carry out regular information gatherings at which the public is informed about private precautionary measures, etc. (Petrow et al. 2006). Since private homeowners fear a decrease in housing values, flood marks at public buildings and infrastructure could set a good example (Umweltamt Dresden, personal communication). Emergency plans on all levels have to be updated and exercises undertaken regularly. A standard hazard and risk mapping system including extreme events as well as an uniform strategy at all planning levels and for all states of Germany is needed (Petrow et al. 2006). The implementation of flood management in guidelines and legislation supports the consideration of the flood risk in decision making. Measures with long-lasting effects like private building precautionary measures or structural measures are advantageous, especially if the technique is robust and still able to function in decades (Umweltamt Dresden, personal communication). However, it is an important challenge for the future to keep preparedness at a high level also without recurrent flood experiences.

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