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Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany

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Abstract

The German Freestate of Saxony was the most affected region during the severe flood in August 2002, and damage to companies was high. A survey of 415 companies representing a variety of sectors and sizes was undertaken to identify deficits in the flood management of companies. In August 2002, preparedness and precaution of companies was low. Additionally, 45% of the companies had not received any flood warning. Consequently, many companies were unable to perform emergency measures successfully. The mean total damage to companies amounted to 1.1 million €. However, due to relatively good flood compensation, recovery advanced quickly. After the flood, preparedness and precaution increased, but there is still significant potential for more precautionary measures. The flood warning system should be further improved. Specific incentive and communication programs should be developed for the service and financial sectors, where preparedness and precaution is weakest, as well as for the manufacturing sector, which has the highest damage potential.

Keywords: Damage, Early warning, Flood experience, Preparedness, Recovery, Response

Index terms: Europe, Extreme events, Floods, Human impacts

1 Introduction

Damage due to disasters has dramatically increased during the last few decades and floods generate the largest economic losses of all natural hazards. In 2002, floods accounted for about 50% of all economic losses due to natural disasters worldwide [*Munich Re*, 2003]. The most severe flood event occurred in Germany, Austria, the Czech Republic and Slovakia in August 2002 along the Elbe and Danube rivers and some of their tributaries. The flood was an extreme event with discharge return periods of 150-200 years at the Dresden gauge, Elbe

River and 200-300 years at the Erlln gauge, Mulde River [*IKSE*, 2004]. Two flood types could be distinguished in Saxony: flash floods affecting smaller catchment areas in the Ore Mountains (Erzgebirge), particularly those of the Weißeritz, Mulde and Zschopau rivers, and a slowly rising riverine flood along the Elbe River and at the confluences with its tributaries [*Ulbrich et al.*, 2003]. Floods of short duration with a relatively high peak discharge [*UNESCO*, 2006], in this case caused by very intense rainfall, were defined as "flash floods" in this study. For instance, the village of Weesenstein on the banks of the Müglitz River was particularly affected by a flash flood. The water level rose by 1 m between 9:30 and 10:30 a.m. local time on 12th of August 2002, and continued to rise at a rate of 0.5 mh^{-1} until the telemetry transmissions failed at 3:45 p.m. [*Ulbrich et al.*, 2003]. This situation was caused by intense rainfall, e.g. 312 mm of rain within 24 hours were measured on the 12th of August at the Zinnwald-Georgenfeld station, which is located at the headwaters. This is the highest amount of daily precipitation ever measured in Germany [*Deutscher Wetterdienst*, 2002]. Detailed descriptions of the flood event were published by *DKKV* [2003], *Ulbrich et al.* [2003], *Engel* [2004] and *IKSE* [2004], for example.

The total flood damage in Germany is estimated to have been 11.6 billion €, with an estimated 8.6 billion € of damage in Saxony, the most affected federal state [*BMI*, 2002; *SSK*, 2003]. About 13,000 companies were affected in Saxony, causing direct damages of 1.9 billion € [*SSK*, 2004], and incalculable losses due to business interruptions and limitations. The tremendous damage revealed weaknesses in existing regulations and organizational structures in various sectors. After the flood, many programs were launched and attempts made to improve German flood risk management. Two examples related to the early warning and the flood insurance system shall be described in more detail here, others were analyzed and published (e.g. *DKKV* [2003]).

After August 2002, the insufficient flood forecasts and lack of timely warning were criticized and an improvement in the flood warning system was called for in Germany. More specifically, it was felt that the weather warnings of the German Weather Service had either come too late or had been too imprecise. Although the models had provided information about impending extreme weather situations, their accuracy had evidently not been sufficient for an earlier warning [*Rudolph and Rapp*, 2003]. 214 flood report and forecasting gauges were located in the Elbe River catchment area, but many had failed due to extreme flooding and power blackouts. Additionally, the flood forecasting model for the Elbe River had been based on a regression analysis of discharges and had thus used discharges at upstream gauges as input data. Discharges had been calculated from the water levels by means of rating curves. In August 2002, the flood forecasts were hampered by extremely high water levels, for which the forecasting model had not been calibrated and the rating curves had not been defined. Therefore, predictions of the downstream discharges and water levels had been overassessed by far. Furthermore, the forwarding of flood reports had been delayed at intermediate stations, the feedback of the rural districts to the flood forecast centers had been poor, and because of the responsibility of different flood forecast centers for the same river area (e.g. at the Mulde River), forecasts had not been consistent with each other [*von Kirchbach et al.*, 2002]. After the 2002 flood, many initiatives were introduced to improve the flood warning system. For instance, the German Weather Service (DWD) has been further developing and improving its numerical weather forecast models and its warning management. The federal states have started to design the flood warning gauges in a flood-proof manner, and to equip them with back-up data collection, transmission and power supply systems. The flood routing model "ELBA" has been updated with new stage-discharge relationships and new model components. In addition, a new flood forecast model, "WAVOS", has been developed for the Elbe River in Germany and the schedule of releasing warnings has been upgraded. In Saxony, the four existing regional flood centers have been integrated into one state flood center

(Landeshochwasserzentrum LHWZ, www.hochwasserzentrum.sachsen.de) and the water levels measured at the gauges are automatically collected and transferred to that center. If specific water levels are exceeded, an urgent warning is automatically generated which the communities have to acknowledge. Other initiatives have aimed at the introduction or expansion of flood risk mapping schemes in several affected federal states. For example, the Swiss flood hazard mapping scheme [*BUWAL*, 1998] was introduced by the state of Saxony. Further information on flood mapping and early warning systems in Germany after the August 2002 flood has been published by *DKKV* [2003] and *Thieken et al.* [2005b].

Germany is one of the few European countries in which private insurance companies offer natural hazards insurance [*Vetters and Prettenthaler*, 2003]. For companies, commercial property insurance and all-risk policies are available. Additionally, insurance coverage is available for interruption to business, covering fixed expenses as well as lost profit [*Jakli*, 2003]. However, particularly hazard-prone locations are often excluded from flood insurance or are only insured if high premiums are paid. For small companies with an insured inventory of less than 2.5 million €, risk classification is undertaken via the zoning system for inundation (ZÜRS) specifically developed for insurance issues [*Kriebisch*, 2000; *Kleeberg*, 2001] as well as via information about flood damage during the last ten years and the distance to the river. For large companies with high premiums, individual examinations are carried out. After the 2002 flood, conditions of existing insurance contracts were barely altered. However, one third of the insurance companies have announced an increase in insurance premiums and/or deductibles when new contracts are signed [*Thieken et al.*, 2006]. More than 50% of the insurance companies indicated that they would improve their risk assessment, leading to tightened conditions. Although the insurance industry had generally given up its negative attitude towards a compulsory flood insurance after the 2002 flood [*Schwarze and Wagner*,

2004], no agreement between the insurance industry and the German federal states could be achieved.

In Germany, the traditional approach to flood protection was generally characterized by a safety mentality. Protection was aimed at design criteria (for instance, the 100-year flood), without a detailed analysis and debate about the complete spectrum of possible events, failure scenarios and protection objectives. This traditional safety mentality or promise of protection is slowly being replaced by a risk culture. Such a risk culture is based on a comprehensive analysis of the flood risk and an appraisal of potential risk-reducing measures. Further, it takes into account the fact that flood defense systems may fail and it makes preparations for such unexpected crisis situations. A key element is an open dialogue about risk and risk-reducing options, involving all stakeholders [*DKKV*, 2003]. For an efficient, integrated approach, not only public efforts like technical protection measures and an increase in natural retention have to be taken into account. The mitigation potential of companies via flood precautionary measures and response to early warning also has to be investigated and is being increasingly encouraged [*Hayes*, 2004; *Wynn*, 2004]. The previously prevalent separate view of the two main elements of flood risk management, precautionary measures and response, has to be overcome. All aspects of flood risk reduction and disaster response have been integrated into the cycle of disaster management. This means, for instance, that reconstruction after the disaster already has to contain the foundations for improved precautionary measures. Therefore, disaster management should be analyzed following the disaster cycle, which describes the consecutive phases that a society undergoes after it has been struck by a disaster. The concept of the disaster cycle has been widely used and various versions have been published [e.g., *Silver*, 2001; *DKKV*, 2003; *FEMA*, 2004]. Adapted to companies, the phases, preparedness, response, recovery and disaster risk reduction may be described as follows: if companies had already been affected by a flood or were aware of the flood risk, they might

have undertaken building, behavioral or financial precautionary measures such as improving the building structure, developing an emergency plan or taking out flood insurance, respectively. When a flood occurred, emergency measures could be undertaken to further mitigate losses. The type and effectiveness of the response would depend on the preparedness of the companies. For example, companies that had an emergency plan available would probably be more efficient in safeguarding goods or protecting the building(s) against inflowing water than others. The resulting damage would be influenced by the flood characteristics (e.g. water level, flood duration, contamination), but also by the resistance given, which might have been improved by precautionary and emergency measures. During recovery, the affected companies would try to repair the damage and to regain the same production standard as before the disaster happened as quickly as possible. If affected companies were willing to learn from the disaster and invest in disaster risk reduction, precautionary measures could often be implemented without large additional effort when extensive reconstruction needs to be undertaken anyhow.

To improve the flood management of companies, a comprehensive analysis of the precautionary measures taken in advance and the ability to cope with the actual flood should be undertaken in the aftermath of an event. However, only limited data about companies' flood risk and their management are available. This lack of information was already described by *Ramirez et al.* in 1988, but the situation has not changed much since then. Research about flood damage has concentrated almost exclusively on residential flood damage [*Gissing and Blong*, 2004]. Only a few studies deal quantitatively with the measures companies can undertake to reduce their flood losses [*Smith*, 1981; *ICPR*, 2002; *Kreibich et al.*, 2005a]. Additionally, representative results are difficult to obtain due to the diverse spectrum of companies [*Gissing and Blong*, 2004]. An approach to reducing this high data variability is

the classification of companies into subgroups according to economic sectors [*Smith*, 1981; *Parker et al.*, 1987; *Merz et al.*, 2004].

In order to gain more knowledge about precautionary measures taken by companies and their abilities to cope with the adverse effects of floods, a survey was undertaken among companies in Saxony affected by the August 2002 flood. Specifically, the aim of this study is the identification of improvement potential in the flood management of companies. The companies were divided into sectors to reduce data variability within the subgroups and to identify differences between sectors. Hence, the sectors with the largest improvement potential will be identified and recommended for specific measures and programs.

2 Material and Method

2.1 Survey

On the basis of information obtained from the affected communities and districts, lists of affected streets in Saxony (Fig. 1) were comprised and with the help of the telephone directory (yellow pages) a site-specific random sample of 1500 companies was generated. Since the manufacturing sector was strongly underrepresented, 342 additional addresses of manufacturing companies were randomly selected in the same manner and added to the sample. From this sample, 307 interviews were completed in October 2003. However, large companies were barely included in the dataset. After the Saxon chambers of industry and commerce provided 183 addresses of affected large-scale companies, additional interviews were undertaken in May 2004, resulting in 108 interviews, so that altogether 415 interviews were completed. Thus, the selection of companies was not representative, since it seemed more important to cover a broad range of companies in terms of size and sector.

A new standard questionnaire was set up for this investigation, incorporating suggestions from *Parker et al.* [1987], *MURL* [2000], Schmidtke (pers. comm., 2002), IHK (pers. comm.,

2003), personal experiences collected from a survey of private households after the 2002 flood [*Kreibich et al.*, 2005b; *Thieken et al.*, 2005a], and a risk analysis study in the Seckach/Kirnau area [*Merz and Gocht*, 2001]. The questionnaire addressed the following areas:

- characteristics of the company: sector, number of employees, business volume in 2001, lay-out (e.g. located in several rooms, stories or buildings), size of premises, ownership structure related to the building(s), number of buildings at the affected site, total outside storage space, length of time at the location, position of the person being interviewed.
- flood characteristics: name of the river that caused the damage, flood depth above ground surface, flood duration, contamination.
- flood warning: source of warning, lead time.
- emergency measures: efficiency of safeguarding equipment as well as goods, products and stock (assessed on a rank scale), kinds of other measures, time spent on emergency measures, number of people involved, cost of emergency measures, reasons why no emergency measures were undertaken (if applicable), details of the emergency plan (e.g. time and people needed).
- clean-up: duration and number of people involved, clean-up costs.
- characteristics of and damage to the building(s): value of the building(s) (preferably as current market value), ground-floor space, number of cellar and stories, total cellar space, utilization of attic, flood-affected stories, total amount of building damage.
- characteristics of and damage to contents: total value of equipment, vehicles, goods, products and stock (preferably as current market value), total amount of damage to equipment, vehicles, goods, products and stock, type and amount of the most expensive damage to the equipment.

- interruption to business (i.e. no business activities, e.g. production, service, possible due to the flood): amount of damage due to business interruption, duration of business interruption, dependency on suppliers.
- recovery: length of time until resumption of normal business operations (i.e. time of business limitation), identification of restrictions still existing at the time of the interview, assessment of recovery at the time of the interview (assessed on a rank scale), amount of loss compensation and satisfaction with the compensation procedure.
- preparedness: kinds of precautionary measures that had been taken i.e. financial precautionary measures (flood insurance), behavioral precautionary measures (emergency exercises; emergency plan), building precautionary measures (flood-adapted building use; availability of water barriers; flood-adapted building structure; utilities, sensitive items, substances and equipment located upstairs; flood proof air conditioning/exhaust-air vents; safeguarding of hazardous substances; avoidance of oil heating or usage of a flood proof oil tank; flood proof tanks, silos and other storage containers), relocation to a safe area or other precautionary measures undertaken before the flood, after the flood, planned within the next six months, not intended or not applicable.
- flood experience and awareness: number of previously experienced flood events, last event, most severe event, knowledge about the flood hazard of the company, estimated likelihood of being affected by future floods (assessed on a rank scale).

A complete interview contained about 90 questions, but not all questions were applicable in all cases. As the questioning was undertaken by experienced interviewers and since, for most questions, a list of possible answers was given (with either a single answer or multiple answers possible), an average interview lasted only about 15-20 minutes. For some questions,

open answers were requested. Three questions asked people 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 meanings of the end points of the scales were given to the interviewee. The intermediate ranks could be used to graduate the evaluation.

The computer-aided telephone interviews were undertaken with the VOXCO software package by the SOKO-Institute for Social Research and Communication (www.soko-institut.de), Bielefeld. Before the start of the survey, the interviewers had a one-day training session, given by hydrologists and sociologists. They were given sufficient background information about the survey and each question was discussed, before they undertook some supervised test interviews. The survey was undertaken by about 10 interviewers working in parallel in a call center. Continuous quality control was assured via random unnoticeable observation of the interviews by the supervisors. The VOXCO software guides the interviewers through the questionnaire. The next question appears only if an answer to the previous question is keyed into the system. If one answer makes some following questions inapplicable, these are automatically not stated, e.g. if the interviewee states that no emergency measures had been undertaken, all following questions concerning this topic are skipped. To avoid errors, only meaningful answers were accepted by the system. Wherever possible, answers were cross checked, e.g. if the given outside storage area is larger than the given area of the premises, the interviewer was informed about this contradiction and prompted to clarify the situation. The person who had the best knowledge about flood damage to the company was always questioned. In 70% of the cases this was a member of the management board.

The answers keyed in during the interviews were automatically saved in SPSS data format. As far as possible, further plausibility checks were made after the interviews. Since a

significant proportion of the resulting data is not normally distributed, the mean and the median are given. Statistical analysis was undertaken with the software SPSS for Windows, Version 11.5.1. Significant differences between two independent groups of data (e.g. flood type areas) were tested by the Mann-Whitney-U-Test [*Norušis*, 2002]. Significant differences between three or more groups of data (e.g. sectors) were tested with the Kruskal-Wallis-H-Test [*Norušis*, 2002]. It tests the null hypothesis that all groups possess the same probability distribution against the alternative hypothesis that the distributions differ, that is, one or more of the distributions are shifted to the right or left of each other. For both tests a significance level of $p < 0.05$ was used.

2.2 Data set

The resulting data set contains 415 completed interviews representing a variety of sectors, company sizes, building owners and leasers (Table 1). The total loss, including damage to building(s), equipment, vehicles, goods, products and stock and business interruption could be calculated for 179 companies. The companies were classified into NACE (Nomenclature statistique des Activites economiques dans la Communaute Europenne) classes according to the European statistical classification of economic activities in the European Community [*Eurostat*, 2002]:

- agricultural sector: agriculture, hunting, forestry and fishing (NACE classes A-B).
- manufacturing sector: manufacturing, construction, mining and quarrying, electricity, gas and water supply (NACE classes C-F)
- commercial sector: wholesale and retail trade, repair of motor vehicles, motorcycles and personal and household goods, hotels and restaurants, transport, storage and communication (NACE classes G-I)
- financial sector: financial intermediation, real estate, renting and business activities (NACE classes J-K)

- service sector: public administration and defense, compulsory social security, education, health and social work, other community and social and personal service activities, activities of households, extra-territorial organizations and bodies (NACE classes L-Q)

Most interviewed companies belonged to the commercial sector (39%), the fewest to the agricultural sector (2%) (Table 1). For the sake of completeness, the results of the agricultural sector are shown. However, since only seven agricultural companies are included in the data set, statistical analyses of this sector are problematic and results have to be reviewed critically.

Most interviews were completed for companies with up to 10 employees (62%), only 21% had more than 50 employees (data not shown). The median was 6 and the mean 37 employees (Table 1). The manufacturing sector included the largest companies in respect to the number of employees and business volume. In this sector, most companies owned their buildings. In contrast, ownership rate was lowest in the financial sector. Based on the definition of flood types, 63% of the interviewed companies were located in flash flood areas (Table 1). In most sector-subsets, the percentage of companies in flash flood areas was around 70%. In contrast, in the commercial and financial sectors, only 58% and 51% of the companies were located in flash flood areas, respectively.

3. Results and Discussion

3.1 Flood experience and preparedness before the flood event in August 2002

The companies affected by the 2002 flood along the Elbe River and its tributaries had little flood experience. Only 25% had experienced at least one flood before, and only 13% of the others knew that they were located in a flood prone area (Table 1). Furthermore, as the last

experience with a flood was on average 39 years before, memories of the flood had faded. The floods most often mentioned, when asked about the last experienced flood event, were the floods in July 1954 along the Elbe and its left-sided tributaries (20 entries), in July 1957, e.g. along the Gottleuba and Weißeritz rivers (13 entries), and in July 1958, e.g. along the Zschopau and Mulde rivers (15 entries). Descriptions of these flood events have been published by *Pohl* [2004]. Flood experience was significantly different between the sectors (Table 1). In the manufacturing sector it was highest with 34% flood experienced companies. In the financial and service sector it was lowest with only 14% and 13% experienced companies, respectively.

Before the August 2002 flood event, 49% of all interviewed companies had undertaken at least one precautionary measure (Fig. A1). Significant differences between the sectors existed, with highest preparedness in the manufacturing and agricultural sectors and lowest preparedness in the financial sector. This can be explained on the one hand by flood experience and knowledge, and on the other hand by the sizes of the companies and building ownership [*Brenniman*, 1994; *Kreibich et al.*, 2005a; *Grothmann and Reusswig*, 2006]. The awareness of being located in a flood prone area was most prevalent and flood experience highest in the manufacturing sector (Table 1). None of the interviewed inexperienced companies in the agricultural sector had known that they were located in a flood prone area, but the percentage of experienced companies was, with 29%, second highest of all sectors. In the financial sector, the awareness of being located in a flood prone area was lowest and flood experience second lowest of all sectors. *Kreibich et al.* [2005a] found that companies which own their building(s) and larger companies (many employees, high business volume) tend to undertake precautionary measures more often than others. Therefore, it is not surprising that the manufacturing sector, which contains the largest companies on average and the second highest percentage of building owners, shows a comparatively high level of preparedness. In

contrast, in the financial sector with the lowest level of preparedness, ownership rate was lowest and the average company size was small to medium.

Of all precautionary measures, those related to the building were the most prevalent whilst behavioral measures (i.e. emergency exercises, emergency plans) were the least (Fig. A1). Quite a wide variety of precautionary measures are subsumed under building precautionary measures (see description of questionnaire in section 2.1). For instance, a comprehensive description of efficient building precautionary measures, especially water barrier systems, has been published by *Bowker* [2002]. Different measures are reasonable or applicable, depending on the type of company, e.g. companies that do not store and deal with hazardous substances do not need to undertake special safeguarding measures for hazardous substances. Therefore, there are measures that only apply to some of the companies (e.g. flood proofing of air conditioning/exhaust-air vents) and measures that are reasonable to undertake for all companies (e.g. shielding with water barriers). Fig. A1 includes companies that had undertaken one or more building precautionary measures, irrespective of the number of building precautionary measures applicable to the specific company. For most sectors, the most prevalent building precautionary measure was “flood proofing of air conditioning/exhaust-air vents”, second was “flood proofing of tanks, silos and other storage containers” (data not shown). This may be due to high standards when buying and installing air conditioning systems or exhaust-air vents and to laws and regulations like the statutory order on hazardous incidents. The least popular measure was “flood-adapting the building structure”, i.e. using an especially stable building foundation, waterproof seal the cellar, etc. This may be due to the fact that it requires a large initial investment and does not necessarily provide protection against extreme flood events [*MURL*, 2000]. Detailed investigations of the mitigating effects of the different building precautionary measures revealed that most measures had led to a reduction in mean building damage and all measures had led to a

reduction in median building damage to companies. But differences were not significant, most likely due to the heterogeneity of the companies and the small sample size [*Kreibich et al.*, 2005a].

The lack of popularity of behavioral precautionary measures, which do not seem to be expensive in comparison to some building precautionary measures, may be due to the fact that a certain level of ongoing effort and continued investment is necessary. Emergency plans have to be updated and exercises have to be undertaken regularly. This is in contrast to building precautionary measures, e.g. when flood proof air conditioning is installed, no more additional effort is needed. Additionally, the improvements of the buildings are clearly visible, whereas the improvements in preparation are difficult to judge. For most sectors, emergency plans were available more than twice as often as emergency exercises had been undertaken (data not shown). In total, 42 companies (10%) had had emergency plans available, 18 companies (4%) had undertaken emergency exercises before August 2002. It can be speculated that the popularity of plans in contrast to exercises might be due to the necessity of business interruptions during the time when exercises are undertaken. However, the two measures should not be viewed separately, since emergency plans that have not been tested during emergency exercises may be ineffective. Most importantly, it should be noted that expenditures for flood preparedness and exercises amount to only a fraction of a percent of the commonly very high damage potential of large businesses [*ICPR*, 2002].

3.2 Response to the August 2002 flood

The flood warnings had reached the companies on average 20 hours (median 8 hours) before their premises were flooded (Table 2). However, 45% of the interviewed companies had not been warned at all. 32% had recognized the flood danger through their own observations, 11% had been warned by employees, friends or other companies and 14% by nationwide

news programs. Flood warnings disseminated by the authorities had reached only 25% of all surveyed companies. Official warnings had been spread mainly by loudspeakers, flyers, etc., followed by local radio stations. 7% of the companies had been specifically warned by a direct message from the authorities to their company (data not shown).

Comparing the situation in the flash flood areas with the riverine flood areas, significant differences were only apparent relating to the lead time of the warnings, not concerning the means of warning (except for nationwide news). In the flash flood areas, companies had been warned on average only 10 hours before the flood reached them, in the riverine flood areas it was 34 hours before (Table 2). This is in accordance with Thieken et al. (Thieken, A. H., H. Kreibich, M. Müller and B. Merz, Coping with floods: A survey among private households affected by the August 2002 flood in Germany, submitted, 2006 to Hydro. Sci. J.) who stated that warnings to private households had been disseminated in large parts of the Ore Mountains (flash flood area) only a few hours before houses were flooded, whilst along the Elbe River (riverine flood area) a lead time of several days had been possible. The percentage of companies that had not been warned at all was similar in both areas, as well as the percentage of companies that had been warned by the authorities (Table 2). This is in contrast to findings in the residential sector, where only about 12% of the households along the Elbe River and almost 40% along the Elbe tributaries had not been warned at all (Thieken et al., 2006b). In terms of warning time and means of warning, there are no significant differences between the sectors (data not shown).

The percentage of companies that had undertaken emergency measures (67%) is even larger than the percentage that stated that they had been warned, which implies that some companies had become aware of the danger of flooding and had acted without receiving a warning. The main aim of emergency measures is the safeguarding of equipment, goods, products or stock,

which might be achieved by moving them to flood save areas or by using water barriers to prevent the water from entering the building. The percentage of companies that undertook emergency measures and the resulting costs were not significantly different between the sectors, in contrast to the number of people involved and the time spent (Table 1). In the manufacturing sector, the greatest number of people was involved and a long time was spent on emergency measures, which correlates with the highest number of employees in this sector. In the service sector the fewest people were involved and in the financial sector the shortest time was spent on emergency measures. These differences might also be due to the "nature" of the business, e.g. it is much more time-consuming to dismantle and relocate large machinery and numerous goods, products or stock in a manufacturing company, than computers and ring binders which might be the predominant inventory in the service and financial sectors.

Whether emergency measures can reduce flood damage depends on their effectiveness. Companies that had undertaken emergency measures were asked whether they were able to save their equipment or their goods, products or stock completely, largely, to a limited extent or not at all. Only 7% of the companies that had undertaken emergency measures were able to save their equipment completely, and 10% were able to save their goods, products or stock completely (Fig. A2). Large parts of equipment and goods etc. could be saved by 21% and 18%, respectively. Despite the efforts undertaken, 28% of the companies were not able to save any equipment and 34% were not able to save any goods, products or stock. Differences between the sectors concerning the effectiveness of emergency measures undertaken were only significant concerning goods, products or stock. Measuring the saving of large and complete parts of goods, products or stock as success, the manufacturing and commercial sectors contain the largest percentage of successful companies. The service sector contains the largest percentage of companies that were able to save their goods, products and stock

completely, but it also contains the largest percentage of companies that were not able to save anything.

The comparison of damage to goods, products or stock of companies that had undertaken their respective emergency measures successfully with the other companies reveals a significant damage mitigation of 52%, on average (Fig. 2). Successfully saving the equipment led to a significant average reduction of damage to equipment by 28%. It is difficult to make generalizations about the positive effects of emergency measures, since they depend on the intensity of the flood event. However, the *ICPR* [2002] presumes a 50-75% reduction of damage due to emergency measures in industry and trade.

To investigate in more detail, the factors that may support the effectiveness of emergency measures undertaken, the companies were split into two subgroups, the ones that had undertaken emergency measures effectively and the remaining companies. Companies were included in the first group when they were able to save their equipment or their goods, products and stock completely, and also when they were able to save their equipment and goods, products and stock largely. Only relatively recent flood experience seems to support effective emergency measures (Table 3). General flood experience and knowledge about the flood hazard were not significantly different between the two groups. This is in accordance with the findings of *Burn* [1999] and *Yeo* [2002], that prior experience with flood events is most useful when it was received recently. As expected, if an emergency plan was available, measures could be undertaken more effectively (Table 3). But surprisingly, the emergency exercises undertaken did not differ significantly between the two groups. Warnings, particularly those from authorities, were favorable factors, as well as relatively long lead times (Table 3). For instance, the companies that were able to save their equipment or goods, products or stock completely, had had average lead times of at least 15 hours (Fig. 3). In

contrast, the companies that were not able to save anything at all had had average lead times of less than 10 hours. Additionally, building owners and large companies seemed to be more efficient with their emergency measures (Table 3). However, flood damage is not only influenced by the vulnerability, but also by the flood hazard, specifically by the intensity [*Mileti*, 1999; *Merz and Thieken*, 2004]. Therefore, companies that had been affected by high water levels had more problems undertaking effective emergency measures than those exposed to lower flood water levels (Table 3).

Nonetheless, 32% of all interviewed companies had not undertaken any emergency measures (Table 1). The main reason, stated by 87% of these companies, was that it was too late to do anything. This corresponds to the 74% of all interviewed companies that stated that they could have undertaken (more) emergency measures, if the warning had reached them earlier. A study in the residential sector revealed the same result, i.e. the main reason why people did not perform emergency measures was lack of time, and many affirmed that they could have done more if they had been warned earlier (Thieken et al., submitted, 2006). This underscores the fact that early warning is an important precondition for the effective performance of emergency measures. The second most often stated reason, why no emergency measures had been undertaken, was that it was not possible to reach the premises of the company since the access road had been interrupted. Possibly it might have been too late as well, but this can not be judged from the companies' answers. Anyhow, a great amount of damage to infrastructure had occurred. More than 750 km of rural, county and state roads as well as 585 bridges were damaged in Saxony alone [*IKSE*, 2004]. Still, 8% of the companies had underestimated the flood hazard. These problems seem to have been similar for all sectors, since no significant differences are apparent.

3.3 Flood losses and recovery

The flood in August 2002 was the most severe flood ever experienced for 71% of the interviewed companies that had experienced a flood before. The mean total damage amounted to 1.1 million € (median 0.2 million €) (Fig. 4). Mean values are consistently higher than the median values, i.e. damage data show a strongly skewed distribution. Means are dominated by a few companies with very high damage; only 16% of the 179 companies for which total damage could be calculated experienced total damage of 1.0 million € or above. The highest total damage in our survey amounted to 31.0 million €, the second highest to 21.5 million €, followed by three companies with more than 10.0 million €.

Losses differ significantly between the sectors, with the highest total damage in the manufacturing sector and the lowest in the agricultural sector (Fig. 4). This is in accordance with the findings of *Merz et al.* [2004], who reported highest total damage to the infrastructure and in the manufacturing sector and lowest total damage in the agricultural sector. This difference is mainly due to the different amounts of assets accumulated in the sectors. The manufacturing sector, with the highest total damage, is also the sector with the highest business volume (Table 1). The relative damage to building(s), equipment and goods, products or stock, which is independent from the absolute assets affected and is therefore better able to show the effects of preparedness, precautionary measures, etc., reveals a different ranking of sectors (Table 1). For most sectors, damage to building(s) represents on average the highest percentage damage and damage to vehicles the lowest (Fig. 4). Still, there are significant differences between sectors, e.g. in the manufacturing sector, the building damage represents 32% of the total damage in contrast to the service sector where it represents 63%. This is in contrast to results based on German flood damage data using the following damage categories: damage to buildings, movable inventory and fixed inventory [*Merz et al.*, 2004], where total damage in the manufacturing and service sectors were dominated by damage to movable inventory. Damage to equipment is also very important in

the manufacturing sector, whereas for the commercial, financial and service sectors the damage due to business interruption is the second most important damage type (Fig. 4). Unfortunately, due to a lack of responses, calculating the damage ratio, i.e. the relative damage (damage divided by the current market value), was only possible for a few companies and the three damage types: building(s), equipment and goods, products or stock (Table 1). The accuracy of the responses relating to current market values could not be verified, nevertheless Table 1 gives an idea of the damage ratios, which are significantly different between the sectors for equipment and goods, products or stock. The agricultural and manufacturing sectors have the lowest mean damage ratios. The financial sector has the highest mean damage ratio for equipment and the service sector the highest mean damage ratio for goods, products or stock.

Duration of flooding, business interruptions and business limitations significantly differ between sectors (Table 1). Interruption to business means that no business activities, such as production or service, are possible. Reasons for business interruptions are, for instance, lifeline disruptions such as lack of electricity, water or communication links; destruction of key machinery for the production process; or a lack of raw material due to transport disruptions or problems at the ancillary industries. Business limitation means that the business is operating, but not at a normal level due to ongoing restrictions such as unusable building areas, storage areas or machinery which leads to lower productivity or business volume. The average duration of interruption to business is lowest in the service and agricultural sectors, but the mean duration of business limitation is longest in both of these sectors. In the manufacturing sector, mean duration of business limitation is lowest. The mean duration of business interruption is longest in the commercial sector. For all companies, the average duration of flooding was 4.7 days, the mean duration of interruption to business was 43.1 days and the average duration of business limitations was 92.1 days (Table 1). Correlations

between these three duration times are weak, but the maximum water level at the premises had a strong impact on the duration of business interruption and business limitation. An explanation might be that, if equipment is destroyed by a high flood water level, it doesn't make much difference how quickly the water is pumped out. The main limitation is the time needed for repair or replacement of the equipment. Therefore, *Parker et al.* [1987] used the water level as a factor for estimating the length of time of business interruption in different sectors, and *Booysen et al.* [1999] suggested a correlation with the return period of the flood.

After the August 2002 flood the German government launched a 7.1 billion € emergency fund for reconstruction (Sonderfond Aufbauhilfe). Furthermore, money from the EU solidarity fund and EU structure fund (444 million €), donations (350 million €) and insurance compensation (1.8 billion €) were available for loss compensation [*Mechler and Weichselgartner*, 2003; *Schwarze and Wagner*, 2004; *DZI*, 2004]. On average, companies received 426,000 € compensation from government funds, donations or insurance compensation, which covered on average 45% of their damage (Table 1). Not only absolute compensation was significantly different between sectors (which was expected due to the significantly different amounts of total damage), but also the percentage of damages that was compensated. Both average total damage and average damage compensation were highest in the manufacturing sector, the percentage damage compensated was, with 45%, only medium (Table 1). The financial sector received, on average, the second lowest damage compensation and had the lowest percentage damage compensated. The highest percentage damage compensated was in the commercial and agricultural sectors.

To gain more information about the state of recovery, companies were asked to compare the state of their company before the flood and at the time of the interview, and to evaluate the difference on a scale from 1 (= meanwhile, damage is completely eliminated) to 6 (= there is

still considerable damage). At the time of interview, i.e. about 14 and 21 months after the flood, 65% of the companies evaluated their recovery status with a “1” or “2”, i.e. had already recovered well (Fig. A3). A score of “5” or “6”, showing insufficient recovery, was only given in 10% of the cases. Nevertheless, 38 companies stated in their interview (33 in October 2003, i.e. 14 months after the flood; 5 in May 2004, i.e. 21 months after the flood), that they were still struggling with business limitations. Main limitations were due to damage to building(s) (21 entries), equipment (15 entries) and other items (15 entries, multiple answers possible), that had not yet been repaired or replaced. Since there are no significant correlations between the state of recovery and total damage, nor with percentage damage compensated, it is not surprising, that there are no significant differences concerning the recovery between the sectors (Fig. A3).

3.4 Lessons learned and disaster risk reduction

The flood motivated a relatively large number of companies to undertake private precautionary measures (Fig. A4). As was the case before the flood, building precautionary measures were most popular: 39% of the companies had undertaken building precautionary measures after the flood and an additional 6% were planning to undertake such measures within the next six months, at the time of the interview. The service sector had best improved its building precautionary measures, so that it is now on a comparatively high level together with the agricultural and manufacturing sectors. Also, quite a few companies in the financial sector undertook building precautionary measures, but this sector still remains the one with the lowest proportion of companies with building precautionary measures. 15% of the companies undertook behavioral precautionary measures after the 2002 flood, 12% were still planning to do so. However, behavioral precautionary measures remained quite unpopular, with 61% of the companies not intending to undertake such measures. The highest percentage of companies utilizing behavioral precautionary measures was in the manufacturing sector.

The flood insurance coverage of companies improved after the 2002 flood, but 25% of the companies stated that their company was not insurable and 29% did not intend to take out insurance. The least popular measure was the relocation of the company (the flood endangered branch) to a flood safe area. Only 5% of the companies decided to do this after the 2002 flood and 3% were still planning on it. In the financial sector the companies were most mobile, with 10% of companies relocating after the 2002 flood and 8% planning to relocate. Generally, simply the knowledge of the potential flood danger had stimulated companies to invest in precautionary measures before the 2002 flood, but it is not as effective as flood experience by far, as demonstrated by the relatively high number of companies that undertook precautionary measures after the 2002 flood.

4. Conclusion

The flood in August 2002 was an extreme event. Most affected companies had never experienced a flood before and water levels were exceptionally high in many areas. Nevertheless, valuable conclusions can be drawn from this case study investigating 415 companies of various sectors and sizes, for the flood risk management of companies.

In the case of a flood event, most companies undertake emergency measures. But, whether these measures actually reduce flood damage depends on their effectiveness. For instance, successfully saving the equipment led to a significant average reduction of damage to equipment of 28% in August 2002. The effectiveness of emergency measures is increased by recent flood experience, emergency plans, reliable warnings with long lead times, and low water levels. Additionally, larger companies that own their buildings(s) seem to be more efficient in undertaking emergency measures. Since we don’t hope for regular floods and don’t want to provoke them by lowering or removing defenses, it is an important challenge to maintain an ongoing state of preparedness over the long term. Means of keeping preparedness

alive are for example public flood risk maps, regular information campaigns, flood marks at buildings or bridges, flood commemoration days, flood museums. Emergency plans should be promoted by authorities and insurance companies. Adequate regulations should be considered for companies with valuable assets located in flood risk areas. The improvement of the flood warning system is also very important, since reliable warnings and long lead times are crucial for the effective performance of emergency measures.

Good flood compensation supports a quick recovery. Many companies undertake precautionary measures after a flood, but still more could be done. Mostly measures related to the building are undertaken. Behavioral measures, i.e. emergency exercises and emergency plans, are unpopular. This is surprising, since these measures are relatively inexpensive, support a continuous risk awareness and emergency plans are useful in various hazardous situations. Therefore, precautionary measures should be strongly promoted especially in the phase of recovery. Then, companies are aware of the flood risk and are easier convinced to invest in flood precaution. Precautionary building measures can often be implemented during reconstruction without large additional effort. Authorities as well as insurance companies should develop specific incentive and communication programs. Precautionary measures could be even defined as requirements for flood compensation.

In nearly all phases of flood management there are significant differences between the sectors. This justifies the classification of companies into sectors, at least for the analysis of flood losses. The manufacturing sector has the comparatively best preparedness and precaution status, but also the highest damage potential. The mean damage ratios for equipment and goods, products or stock are relatively low in this sector. But due to the high assets and business volumes, the total damage is highest in the manufacturing sector. Thus, specific incentive programs for this sector should mainly aim at a reduction of exposed assets and

prevent the establishment and expansion of manufacturing companies in flood prone areas. The financial sector has the highest mean damage ratio for equipment and the service sector the highest mean damage ratio for goods, products or stock. Preparedness and precaution are comparatively weak in these sectors. Therefore, specific incentive and communication programs should be developed to motivate financial and service companies to undertake behavioral and building precautionary measures.

The significant differences between the sectors suggest that this classification may also be suitable for the estimation of flood losses. Additionally, damage models should take more factors besides the water level into consideration, e.g. the damage reducing effects of emergency and precautionary measures. However, the benefits of these measures are strongly dependent on their effectiveness which can barely be assessed ex-ante. Therefore, more research is needed to integrate these findings into improved flood damage models.

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Tables

Table 1 Data summary for the characterization of the companies and their situation during and after the 2002 flood, divided into main economic sectors.

sectors / data	Manufacturing	Commercial	Financial	Service	Agricultural	All sectors
Number of companies*	147	160	59	42	7	415
Number of employees*#	69 (20)	17 (4)	23 (4)	21 (7)	29 (12)	37 (6)
Business volume 2001 [mill €]*#	7.8 (2.0)	5.1 (0.3)	1.3 (0.2)	0.8 (0.3)	1.3 (0.8)	5.5 (0.5)
Size of premises [1000 m²]*#	21.3 (3.6)	17.7 (0.8)	2.4 (0.9)	18.4 (1.1)	127.4 (10.8)	19.0 (1.5)
Building owners [%]*	78	41	25	40	86	53
Located in slow rising flood area [%]	29	43	49	31	29	37
Located in flash flood area [%]	71	58	51	69	71	63
Water level [m]*#	1.24 (1.00)	1.36 (1.20)	1.73 (1.75)	1.38 (1.53)	0.83 (0.43)	1.37 (1.20)
Duration of flooding [days]*#	3.5 (2.0)	4.7 (2.0)	6.4 (4.5)	6.0 (3.5)	5.8 (4.0)	4.7 (2.5)
Companies with knowledge of flood danger [%][1]	16	13	10	14	0	13
Companies with flood experience [%][2]*	34	23	14	13	29	25
Time since last flood event [years]*#	40 (45)	39 (45)	35 (46)	33 (46)	53 (53)	39 (45)
Emergency measures undertaken	74	67	56	59	86	67

[%]						
Number of people involved in emergency measures*#	24 (9)	10 (5)	13 (5)	7 (5)	13 (4)	16 (6)
Time[3] spent on emergency measures [h]*#	14 (6)	13 (5)	8 (3)	14 (5)	19 (16)	13 (5)
Cost[4] of emergency measures [1000 €]#	12.6 (2.0)	5.2 (2.0)	7.9 (1.0)	3.9 (0.5)	1.5 (1.5)	8.6 (2.0)
Number of companies that did not undertake any emergency measures	38	52	26	17	1	134
Companies did not undertake any emergency measures because it was too late [%][5]	95	87	77	88	100	87
Companies did not undertake any emergency measures because the access road was interrupted [%][5]	5	13	27	24	0	15
Companies did not undertake any emergency measures because the hazard was underestimated [%][5]	16	2	8	12	0	8
Companies did not undertake any emergency measures because of other reasons [%][5]	13	19	31	18	100	20
% of companies that could have	68	74	78	81	100	74

undertaken more emergency measures, if they had been warned earlier[6]						
Damage ratios of building(s) [%]#	23 (15)	23 (13)	26 (27)	30 (20)	7 (3)	23 (15)
Damage ratios of equipment [%]*#	28 (20)	60 (59)	63 (72)	32 (24)	14 (3)	49 (40)
Damage ratios of goods etc. [%]*#	51 (50)	66 (83)	54 (42)	70 (75)	37 (25)	59 (60)
Duration of business interruption [days]*#	36 (14)	52 (21)	48 (18)	30 (14)	18 (9)	43 (14)
Duration of business limitations [days]*#	76 (30)	100 (67)	97 (51)	105 (87)	133 (146)	92 (56)
Damage compensation [1000 €][7]*#	708 (70)	347 (26)	95 (17)	181 (23)	56 (27)	426 (31)
Damage compensated [%][8]*#	45 (42)	53 (25)	28 (11)	31 (28)	83 (33)	45 (31)

* significant difference between sectors ($p<0.05$)

given are the mean values and the median in brackets

[1]Percentage of companies that had not experienced a flood before August 2002, but did know that they were located in a flood prone area

[2]Percentage of companies that had experienced at least one flood before August 2002

[3]If the time spent on emergency measures was given in days, 12 working hours were assumed for the calculation of the time spent in hours.

[4]Costs, not including personnel costs, for the people involved in emergency measures

[5]Multiple answers were possible, when stating the reason(s) for not undertaking any emergency measures

[6]irrespective, if the companies had undertaken emergency measures or not

[7]total amount of compensation received, including e.g. government funds, donations or insurance compensation

[8]total amount of compensation divided by the total damage reveals the percentage of damage covered by compensation

Table 2 Answers to the question: “When and how did the company become aware of the danger of flooding?”, given as percentage of all interviewed companies and per flood type area (for the means of warning, multiple answers were possible).

		All sectors	Flash flood area	Slow rising flood area
Number of companies (n)		415	260	155
Lead time of flood warnings [h]	Mean	20	10	34
	Median	8	6	12
no warning [%]		45	48	40
own observation [%]		32	32	33
warning by employees etc. [%]		11	12	8
warning by nationwide news [%]		14	6	26
warning by authorities[1] [%]		25	23	29

[1] The three different means of issuing warnings by authorities are aggregated here: official warnings via loudspeakers, flyers, etc., official warnings through local radio stations, official warnings by direct messages from authorities to companies

Table 3 Selected parameters which are significantly different ($p<0.05$) in the two subgroups of companies: the ones that undertook emergency measures effectively (n=61) and the ones that undertook emergency measures ineffectively (n=210).

	emergency measures undertaken	
	effectively	ineffectively
Average time since last flood event [years]	33	41
% of companies that had an emergency plan available	18	9
% of companies that had not received any warning	25	40
% of companies that were warned by authorities	36	23
Average lead time of flood warning [h]	27	22
% of companies that own their buildings	69	55
Average number of employees	44	32
Average business volume in 2001 [mill. €]	6.1	2.8
Average water level at premise [cm]	115	145

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Figure captions

Fig. 1 Study area in Germany: marked are the zip-code areas where interviews with companies had been undertaken in the State of Saxony.

Fig. 2 Damage to equipment (a) and damage to goods, products or stock (b) of companies which had or had not undertaken emergency measures successfully (bars = means, points = medians and 25-75% percentiles; *significant difference in damage between both subgroups of companies ($p<0.05$)). It was judged as success, if complete or large parts of equipment, or goods, products or stock, respectively, were saved.

Fig. 3 Lead time of the flood warning of companies which had saved their equipment (a) or goods, products or stock (b) completely or not al all (bars = means, points = medians and 25-75% percentiles; *significant difference in lead time between both subgroups of companies ($p<0.05$)).

Fig. 4 Mean damage (total damage, damage to building(s), equipment, vehicles, goods, products and stock, business interruption) and median total damage per sector and for all sectors together. Total and specific damage are significantly different between sectors.

Appendix:

Fig. A1 Percentages of companies which had undertaken precautionary measures before the August 2002 flood, divided into the different economic sectors and types of measures. Concerning the different precautionary measures, multiple answers were possible. For detailed information about the types of measures, see description of questionnaire in chapter 2.1 (*significant difference between sectors ($p<0.05$)).

Fig. A2: Percentage of companies which stated that they saved their equipment (a) or goods, products or stock (b) completely, largely, to a limited amount or not at all. Only the companies which had undertaken emergency measures and which answered that question were taken into consideration.

Fig. A3 Status of recovery at the time of the interview (evaluated on a scale from 1 to 6). There are no significant differences between the sectors.

Fig. A4 Precautionary measures undertaken by companies (all sectors and separate per sector) before or after the 2002 flood event, planned measures, not intended measures or business site not insurable, given in proportion of valid answers (* significant difference between sectors ($p<0.05$)).

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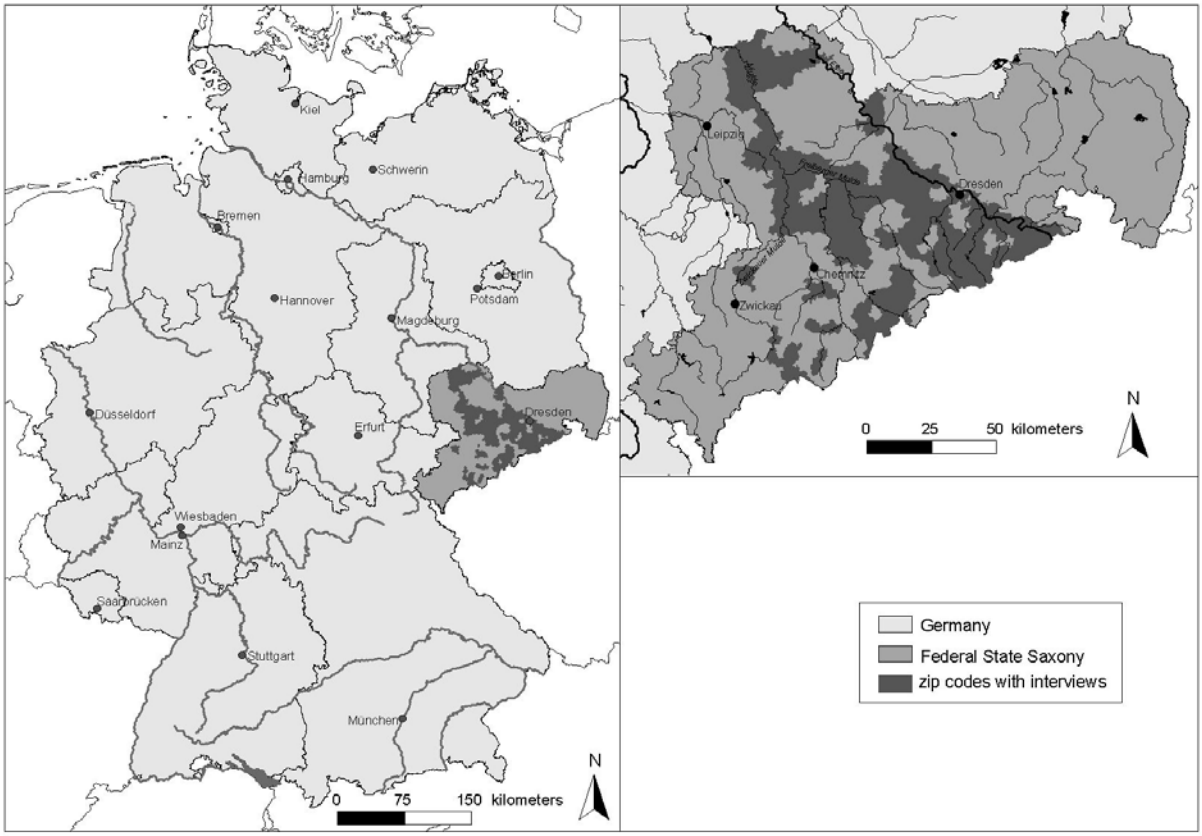
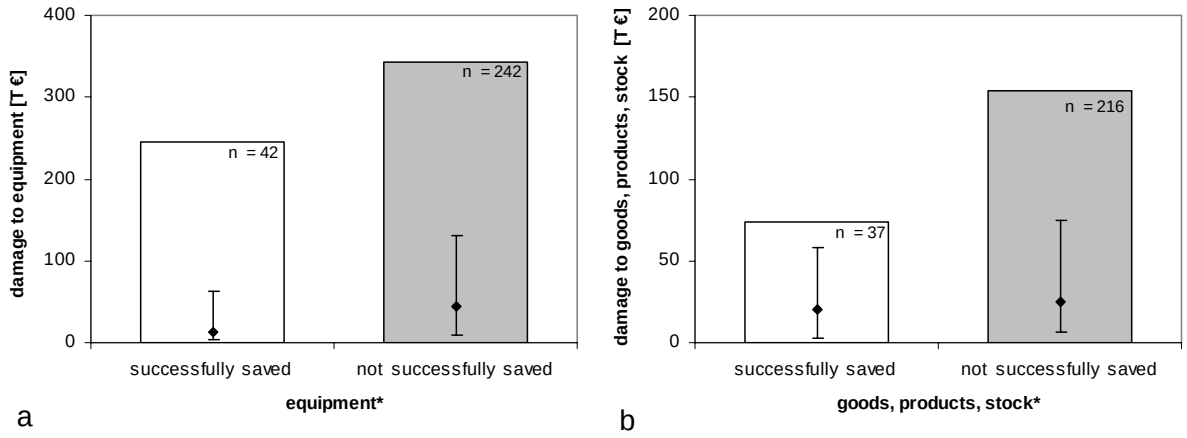


Fig. 1 Study area in Germany: marked are the zip-code areas where interviews with companies had been undertaken in the State of Saxony.

900



905 Fig. 2 Damage to equipment (a) and damage to goods, products or stock (b) of companies which had or had not undertaken emergency measures successfully (bars = means, points = medians and 25-75% percentiles; *significant difference in damage between both subgroups of companies ($p<0.05$)). It was judged as success, if complete or large parts of equipment, or goods, products or stock, respectively, were saved.

910

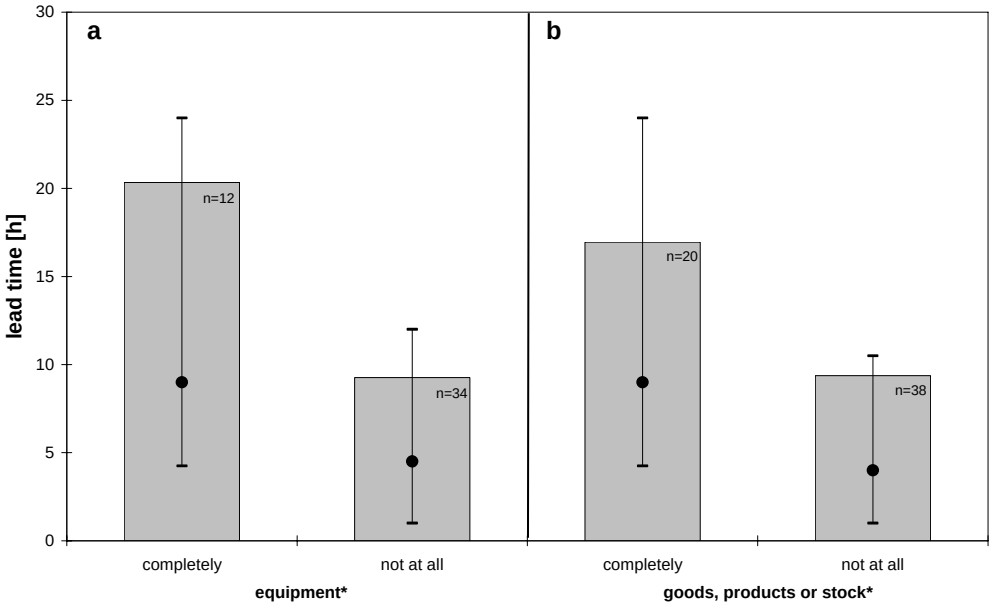


Fig. 3 Lead time of the flood warning of companies which had saved their equipment (a) or goods, products or stock (b) completely or not al all (bars = means, points = medians and 25-75% percentiles; *significant difference in lead time between both subgroups of companies

915 ($p<0.05$)).

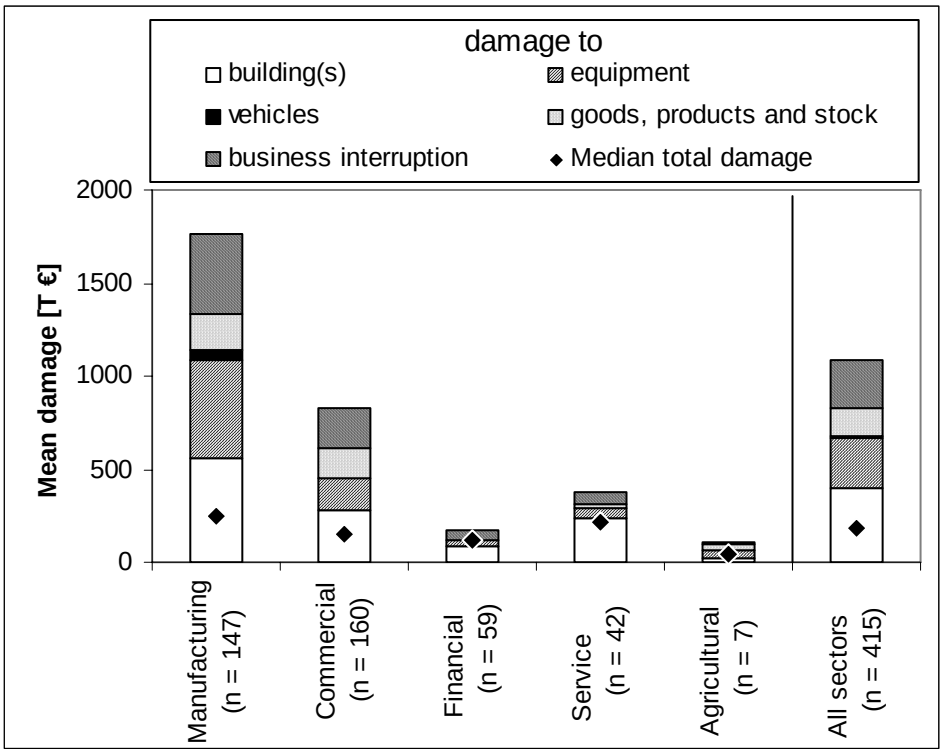


Fig. 4 Mean damage (total damage, damage to building(s), equipment, vehicles, goods, products and stock, business interruption) and median total damage per sector and for all sectors together. Total and specific damage are significantly different between sectors.

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Appendix:

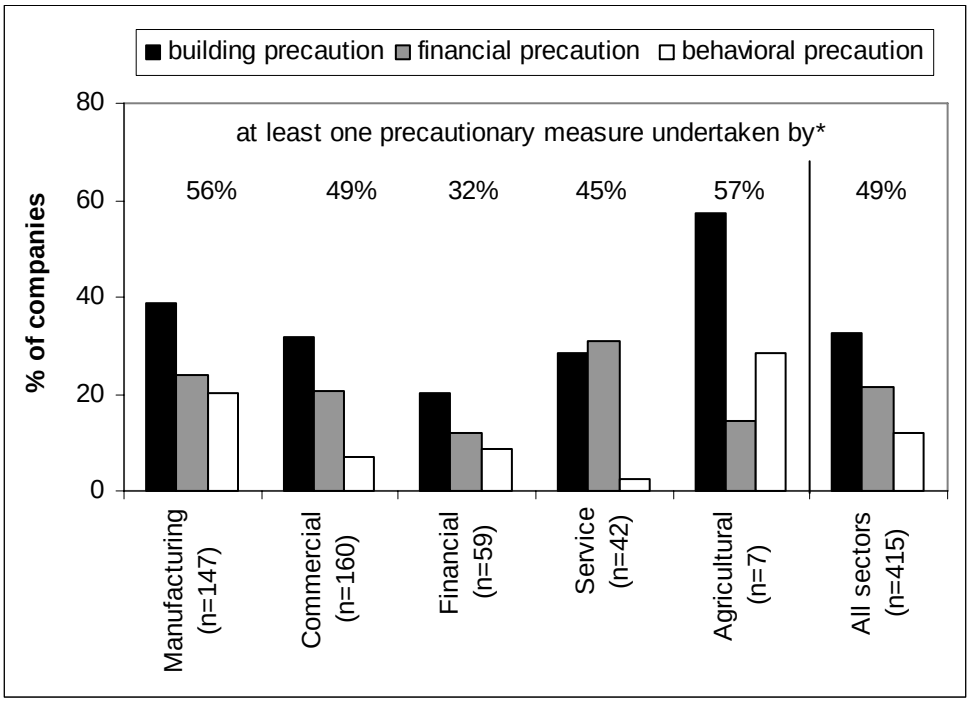
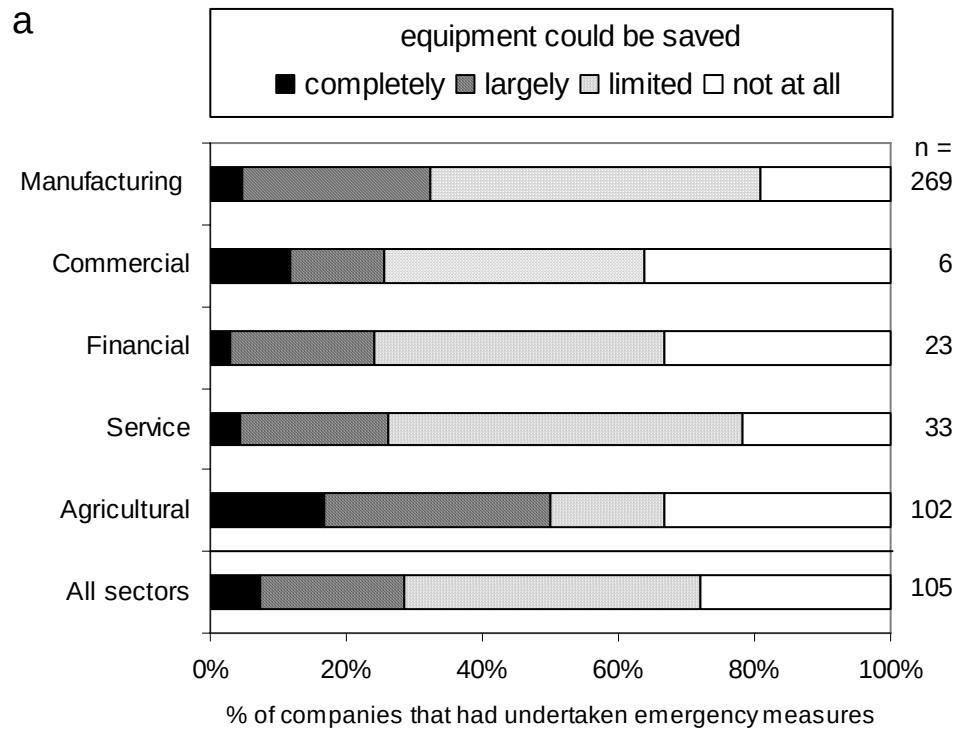


Fig. A1 Percentages of companies which had undertaken precautionary measures before the August 2002 flood, divided into the different economic sectors and types of measures. Concerning the different precautionary measures, multiple answers were possible. For detailed information about the types of measures, see description of questionnaire in chapter 2.1 (*significant difference between sectors ($p<0.05$)).



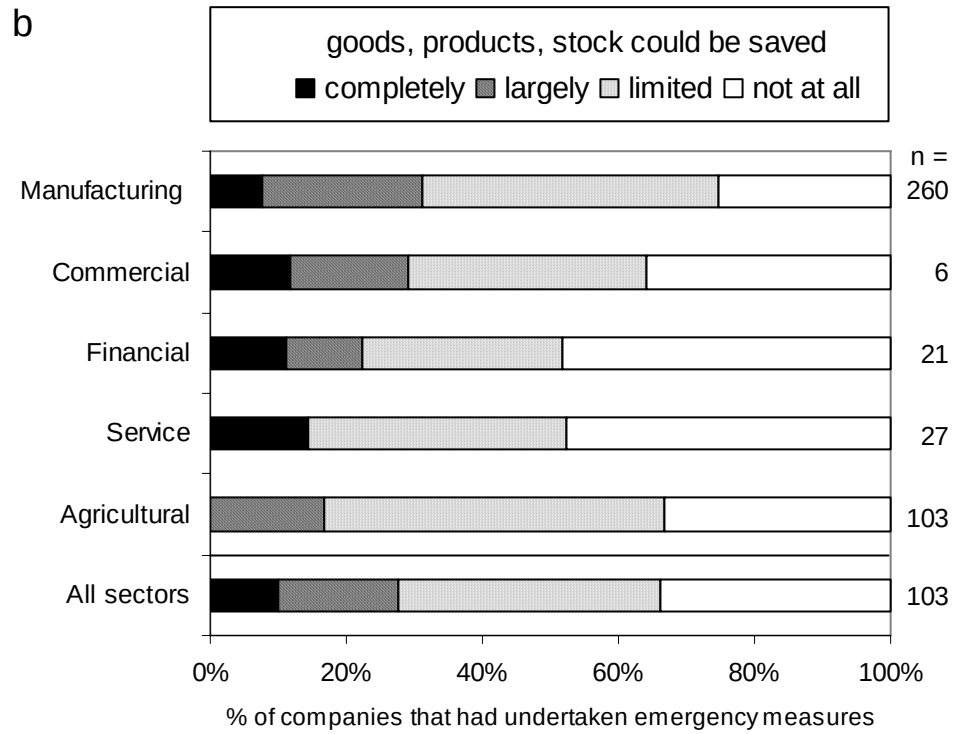


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Fig. A2: Percentage of companies which stated that they saved their equipment (a) or goods, products or stock (b) completely, largely, to a limited amount or not at all. Only the companies which had undertaken emergency measures and which answered that question were taken into consideration.

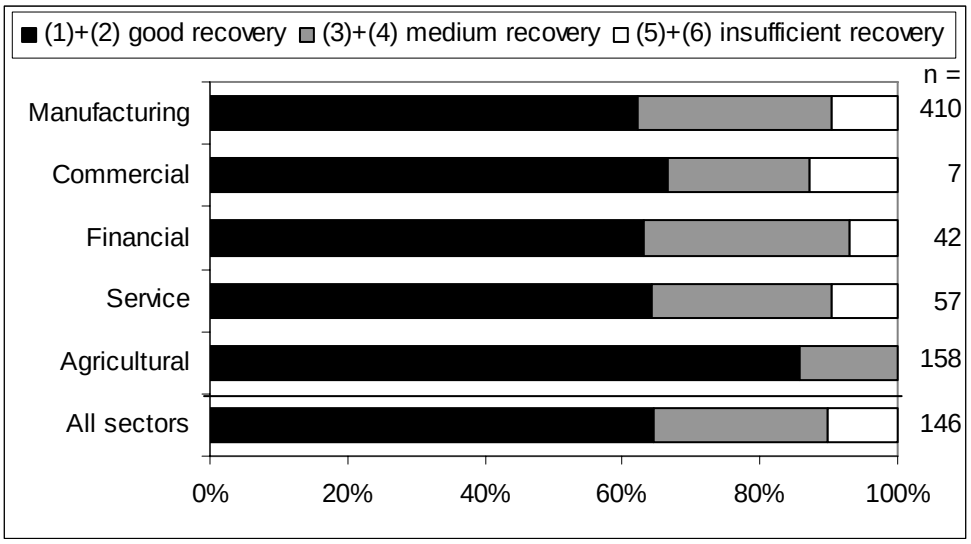

Fig. A3 Status of recovery at the time of the interview (evaluated on a scale from 1 to 6). There are no significant differences between the sectors.

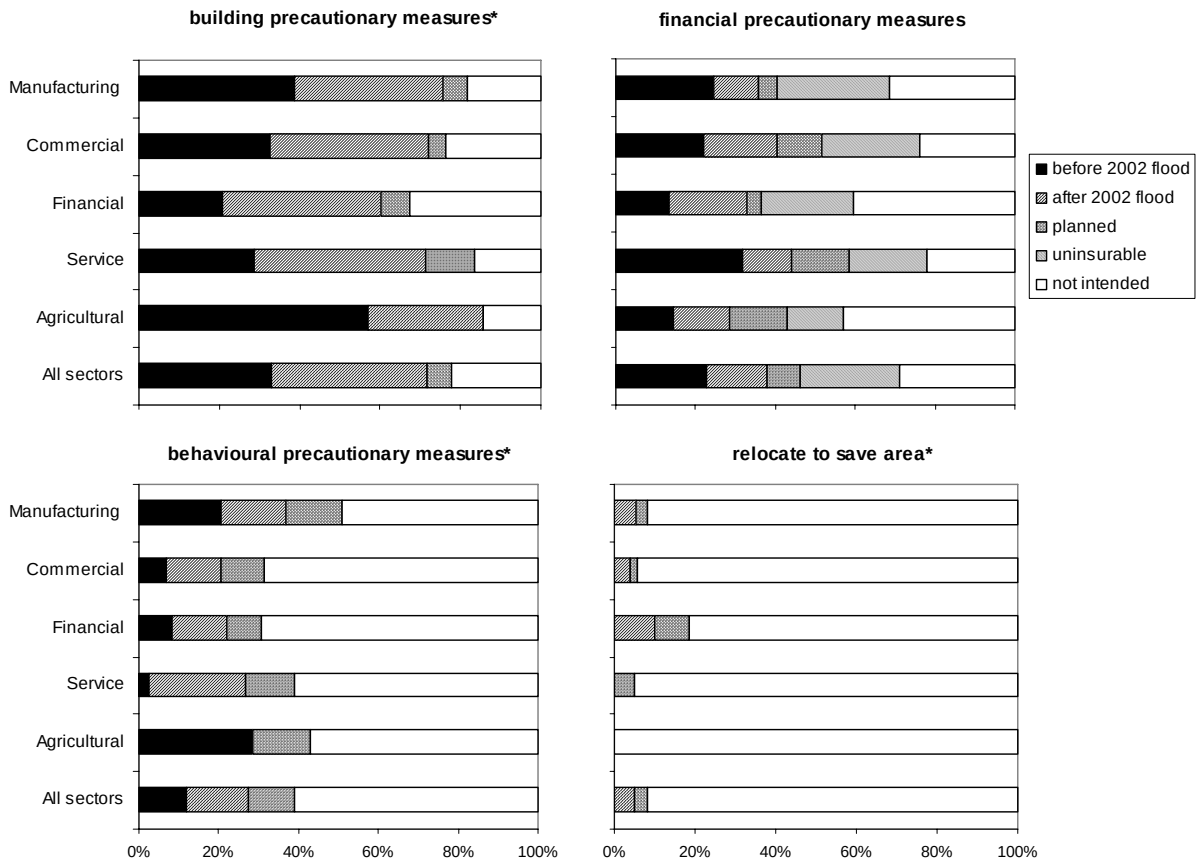

Fig. A4 Precautionary measures undertaken by companies (all sectors and separate per sector) before or after the 2002 flood event, planned measures, not intended measures or business site not insurable, given in proportion of valid answers (* significant difference between sectors ($p<0.05$)).