Floods, flood losses and flood risk management in Germany

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Preface

This thesis consists of twelve independent papers that are based on research in various fields of flood risk analysis at the GeoForschungsZentrum Potsdam (GFZ, Germany's National Research Centre for Geosciences) in the Engineering Hydrology Section. Results from various projects, in which I had the chance to be involved at GFZ from 2000 to 2008, are presented. These projects are:

- German Research Network Natural Disasters (DFNK - Deutsches Forschungsnetz Naturkatastrophen - funded by the German Ministry for Education and Research BMBF from 2000 to 2003, No. 01SFR9969/5),
- Flooding in 2002: Damage of private households (telephone survey funded by DFNK and the Deutsche Rückversicherung AG, Düsseldorf in 2003).
- Lessons Learned from the flood in 2002 - (DKKV-project funded by the German Red Cross in 2003),
- Risk Map Germany (project in the framework of CEDIM, the Centre for Disaster Management and Risk Reduction Technologies, funded by GFZ Potsdam and the University of Karlsruhe since 2003),
- Quantification of economic flood losses in large-scale scenarios (funded by AON Re, Hamburg from 2004 to 2006),
- Methods for the Evaluation of direct and indirect flood losses (MEDIS, funded by the German Ministry for Education and Research BMBF from 2005 to 2008, No. 0330688).

Financial support of all mentioned institutions as well as data provision by many other agencies is gratefully acknowledged. As indicated in the text, most of the papers have already been published elsewhere. However, during the editing process slight changes have been introduced here and there to improve the readability of the thesis.

Nowadays, scientific work cannot be done without the support of and the cooperation with other scientists. Therefore, I would like to thank all my dear colleagues, co-authors and project partners. It was a pleasure to work with you!

In the first place, I would like to thank Prof. Dr.-Ing. Bruno Merz, the head of the Engineering Hydrology Section at GFZ, for introducing the field of flood risk analysis to me and for sharing many ideas and discussing results. Further, I want to thank Dr. Heidi Kreibich and Meike Müller for long, but fruitful discussions about the questionnaires and the surveyed data, Dr. Heiko Apel, Dr. Lucas Menzel and Lorenz Kleist for providing model results as well as Susanne Beurton and Theresia Petrow for not giving up collecting and analysing discharge data. Finally, I would like to thank Prof. Dr. Axel Bronstert for his support at the University of Potsdam.

Last but not least, my special thanks are dedicated to my husband Michael, who supported me in many different ways and encouraged me to finish this thesis.

Annegret Thieken April 2008

Summary

In the last years, severe flooding caused enormous economic losses in Germany, especially in 2002. To reduce future flood losses, flood risk management has to be improved on the basis of a sound knowledge about flood hazard, damaging processes and the effectiveness of mitigation measures. The twelve papers of this thesis contain new results for three topics:

- Description and analysis of the flood hazard in Germany,
- Collection, analysis and modelling of flood losses in the residential sector and
- Opportunities of non-technical flood mitigation measures such as spatial planning, flood insurance and private precaution.

To give an overview of the flood hazard in Germany, the seasonal distribution of annual maximum floods at 481 gauging stations throughout Germany was analysed in the first paper (Beurton and Thieken, submitted). By means of cluster analysis three regions with homogeneous flood regimes were identified: A) a cluster in the western and central part of Germany with distinct winter floods, B) a cluster in north and east Germany, in which the percentage of spring and summer floods is higher than in cluster A and C) a small cluster in southern Germany, which is dominated by pluvio-nival summer floods coming from alpine tributaries.

Taking the catchment of the river Mulde in the south-east of Germany as an example, regional flood patterns in cluster B were investigated in more detail on the basis of discharge series, precipitation fields and flood producing atmospheric circulation patterns (Petrow et al., 2007, Paper 2). Two flood regimes were distinguished: frequent floods during winter and less frequent, but sometimes extreme summer floods. The most extreme flood events in the Mulde catchment were caused by the cyclone Vb-weather regime (TM, TRM), whereas westerly winds produce frequently small floods.

Flood hazard is commonly quantified by flood frequency analyses (FFA). However, FFA is influenced by many uncertainties which are partly addressed in this thesis. Thieken and Menzel (2004, Paper 3) looked at the stability and reliability of FFA in the context of climate change. In several sub-catchments in the German Rhine catchment, a chain of models was applied: 1) two Global Circulation Models driven by the emission scenario IS95a, 2) an expanded downscaling that delivers local time series of precipitation and temperature, and 3) the hydrological model HBV-D that simulated runoff under present as well as scenario climate conditions. The study indicated a potential increase in mean runoff and flood discharge for small return intervals. However, the uncertainty range that originated from the whole model chain was so high that profound conclusions on the development of extreme floods could not be drawn.

The uncertainty of FFA for large return periods (e.g. >100 years) is also influenced by processes in the floodplains, especially if these are protected by embankments. In case of extreme flood events, dikes may breach and cause an inundation of the hinterland. To quantify the influence of dike breaches on flood frequency distributions, a dynamic-probabilistic model was developed and applied to the Lower Rhine in Germany by Apel et al. (2008, Paper 4). For extreme floods, the model simulated significant retention effects due

to dike breaches, which led to significant modifications of the flood frequency curve downstream of the breach locations – an effect that cannot be accounted for by the usually used flood frequency analyses.

Besides meteorological, hydrological and hydraulic investigations risk analyses require an estimation of flood impacts, which is normally restricted to flood losses. Hence, the analysis and modelling of flood losses is focussed on in the second section of this thesis.

In the aftermath of the flood in August 2002, 1697 computer-aided telephone interviews were undertaken in flood affected private households. Thieken et al. (2005, Paper 5) analysed how different variables influenced flood losses to buildings and household contents. Flood impact variables, particularly water level, flood duration and contamination were the most important factors. This group was followed by items quantifying the size and the value of the affected building. Temporal and permanent resistance influenced losses only to a comparatively small fraction, although precaution could significantly reduce flood loss in individual cases. These results were further used to derive the multi-factorial loss model FLEMOps - the Flood Loss Estimation Model for the private sector (Thieken et al., 2008, Paper 7). The model estimates monetary flood losses at residential buildings and household contents on the basis of water level, building type and building quality. An additional model stage (FLEMOps+) can be used to account for effects of private precautionary measures and of the contamination of the floodwater.

FLEMOps was first derived and validated for applications on the micro-scale, i.e. for the estimation of losses considering individual buildings. On the meso-scale, i.e. for loss estimations based on land use units, the model can be used with additional information from census data, an asset data base and land use information. In meso-scale risk analyses there is a spatial mismatch of hazard data that are commonly modelled on a raster level and exposure data that are only available for aggregated units, such as communities. Dasymetric mapping techniques, which use land cover data as ancillary variable, are able to close this gap. In Thieken et al. (2006a, paper 6), countrywide dasymetric maps on the basis of CORINE Land Cover data were created for population density and residential building assets. Model evaluations demonstrated that the maps provided realistic estimates of people and assets exposed to flooding.

To shed some light on the question of required model complexity in flood risk analyses, various model combinations were tested for the municipality of Eilenburg (Apel et al., submitted, Paper 8). Three hydraulic models (i.e. A) linear interpolation of gauge water levels and intersection with a digital elevation model, B) the 1D/2D hydraulic model LISFLOOD-FP and C) a full 2D hydraulic model) were combined with three types of loss models (i.e. I) meso-scale stage-damage functions, II) the meso-scale model FLEMOps+ and III) two micro-scale applications of FLEMOps+). Repair costs for the 2002 flood were estimated at best by LISFLOOD-FP and the meso-scale FLEMOps+. This combination provided a good compromise between data requirements, simulation effort, and an acceptable accuracy of the results.

To reduce future flood losses, risk analyses have to be followed by measures for flood risk reduction. Different measures were analysed after the August 2002 flood within a "Lessons Learned"-study. Paper 9 (Thieken et al., 2004) outlines the methodological framework as well as some results in the fields of hazard mapping and early warning. Before 2002 that there was a huge lack of standardisation in flood hazard mapping, of considering extreme events and of linking hazard zones with land use planning. After the flood there have been first attempts to close this gap which are currently supported by the new EU flood directive.

In 2002, flood warnings were often lacking, too late or incomplete so that affected people could not respond accordingly - especially at the Elbe tributaries. How private households coped with the flood in 2002, was investigated by Thieken et al. (2007, Paper 10). Regional differences in preparedness, response, financial losses and recovery could be attributed mainly to differences in flood experience and flood impact. Knowledge about self-protection, residents' homeownership and household size influenced the extent and type of private precautions taken as well as the residents' ability to perform mitigation measures. In the future, people have to be better informed about hazards and appropriate behaviour. To strengthen risk awareness, hazard maps have to be accessible for the public. Further, flood warnings should include more information about appropriate protection measures and information leaflets for specific groups of people, e.g. tenants, homeowners, elderly people or young families have to be developed.

Besides flood insurance, governmental funding and public donations played an important role for loss compensation in 2002. Therefore, Thieken et al. (2006b, Paper 11) compared insured and uninsured private households. Insured households received loss compensation earlier. They also showed slightly better risk awareness and mitigation strategies. To improve future private loss mitigation, appropriate incentives should be combined with flood insurance. However, there is some evidence that insurance companies do little to encourage precautionary behaviour. Thus, flood hazards and mitigation options are to be better communicated to insurers, as well.

In March 2005 and in April 2006, the Elbe was hit by floods again. Although these events were less severe than in 2002, they allowed Kreibich and Thieken (2008, paper 12) to study changes in risk management and preparedness in the city of Dresden. 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. After 2002, a new flood management concept was developed by the municipal authorities and 67% of the households undertook building precautionary measures. Consequently, flood losses in 2005 and 2006 were significantly lower.

It is an important challenge for the future to constantly maintain loss mitigation measures and to keep preparedness at a high level also without recurrent flooding. Therefore, research should focus on the generation of realistic flood scenarios for different flood types (e.g. flash floods, slowly rising river floods) under current and future climate scenarios, improved flood warning systems, the development and target-specific communication of regionally adapted flood risk reduction strategies as well as the development of methods for risk monitoring.

Zusammenfassung

Hochwasser haben in den letzten Jahren große ökonomische Schäden in Deutschland verursacht, insbesondere im Jahr 2002. Um Hochwasserschäden zukünftig zu vermeiden, ist das Hochwasserrisikomanagement auf Basis von soliden Kenntnissen über Hochwassergefahren, Schadensprozesse und effektive Schutzmaßnahmen zu verbessern. Die zwölf Artikel dieser Arbeit beinhalten neue Ergebnisse in drei Bereichen:

- Beschreibung und Analyse der Hochwassergefahr in Deutschland,
- Sammlung, Analyse und Modellierung von Hochwasserschäden im privaten Sektor sowie
- Möglichkeiten von nicht-technischen Vorsorgemaßnahmen wie Raumplanung, Versicherung und privater Eigenvorsorge.

Um einen Überblick über Hochwasser in Deutschland zu geben, wurde im ersten Artikel (Beurton und Thieken, eingereicht) die saisonale Verteilung der jährlichen Maximalabflüsse an 481 Pegeln aus ganz Deutschland analysiert. Mit Hilfe von Clusteranalysen wurden drei Regionen mit homogenen Hochwasserregimen identifiziert: A) ein Cluster mit vorrangigem Winterhochwasser im westlichen und mittleren Teil Deutschlands, B) ein Cluster im Norden und Osten Deutschlands mit einem erhöhten Anteil an Frühjahrs- und Sommerhochwassern und C) ein kleiner Cluster in Süddeutschland, in dem das Regen-Schnee-Regime der alpinen Flüsse mit Sommerhochwassern dominiert.

Am Beispiel des Mulde-Einzugsgebiets in Südostdeutschland wurde die Hochwassercharakteristik im Cluster B näher untersucht, und zwar auf Basis von Abflussreihen, Niederschlagsfeldern und atmosphärischen Zirkulationsmustern (Petrow et al., 2007, Artikel 2). Zwei Hochwasserregime konnten unterschieden werden: häufige Hochwasser im Winter und seltene, aber manchmal extreme Sommerhochwasser. Die extremsten Ereignisse an der Mulde wurden durch eine Vb-Wetterlage (TM, TRM) ausgelöst, während Westwindwetterlagen eher kleine Hochwasser verursachten.

Im Allgemeinen werden Hochwassergefahren durch Hochwasserhäufigkeitsanalysen (HQ-Statistik) quantifiziert. Die HQ-Statistik ist jedoch mit vielen Unsicherheiten behaftet, die zum Teil in dieser Arbeit angesprochen werden. So untersuchten Thieken und Menzel (2004, Artikel 3) die Stabilität und Zuverlässigkeit der HQ-Statistik im Kontext von Klimaänderungen. In mehreren Teileinzugsgebieten des deutschen Rhein-Einzugsgebietes wurde eine Kette von Modellen angewendet: 1) zwei globale Klimamodelle, angetrieben vom Emissionsszenario IS95a, 2) ein „Expanded Downscaling“, das lokale Zeitreihen mit Niederschlag und Temperatur bereitstellt, sowie 3) das hydrologische Modell HBV-D, das sowohl mit gegenwärtigen als auch mit Szenario-Klimabedingungen Abfluss simuliert. Die Studie zeigt einen potentiellen Anstieg des mittleren Abflusses und des Hochwasserabflusses bei kleinen Jährlichkeiten. Die Unsicherheitsmarge aus der gesamten Modellkette war jedoch so groß, dass Schlussfolgerungen über die Entwicklung von extremen Hochwassern nicht gezogen werden konnten.

Die Unsicherheit der HQ-Statistik für große Wiederkehrintervalle (von z.B. über 100 Jahren) wird auch durch Prozesse in den Flussauen beeinflusst - insbesondere, wenn diese durch Deiche geschützt sind. Bei extremem Hochwasser können Deiche brechen und das Hinterland überfluten. Um den Einfluss von Deichbrüchen auf Hochwasserhäufigkeiten zu untersuchen, wurde von Apel et al. (2008, Artikel 4) ein dynamisch-probabilistisches Modellsystem entwickelt und auf den Niederrhein in Deutschland angewendet. Für extreme Ereignisse simuliert das Modell deutliche Retentionseffekte durch Deichbrüche, die zu signifikanten Änderungen der Hochwasserhäufigkeitskurve unterstrom der Bruchstellen führen – ein Effekt, der durch die herkömmliche HQ-Statistik nicht abgebildet werden kann.

Neben meteorologischen, hydrologischen und hydraulischen Untersuchungen erfordern Risikoanalysen auch eine Abschätzung der Hochwasserauswirkungen, die meistens auf Hochwasserschäden beschränkt werden. Daher bildet die Analyse und Modellierung von Hochwasserschäden den Schwerpunkt im zweiten Teil dieser Arbeit.

Im Nachgang des Augusthochwassers 2002 wurden computer-gestützte Telefonbefragungen in 1697 betroffenen Privathaushalten durchgeführt. Thieken et al. (2005, Artikel 5) analysierten, wie verschiedene Variablen Hochwasserschäden an Gebäude und am Hausrat beeinflussten. Größen der Hochwassereinwirkung wie Wasserstand, Hochwasserdauer und Kontamination waren die wichtigsten Einflussfaktoren. Dieser Gruppe folgten Variablen, die die Größe und den Wert des betroffenen Gebäudes quantifizierten. Temporäre und permanente Schutzmaßnahmen beeinflussten die Hochwasserschäden insgesamt vergleichsweise wenig, obwohl Schutzmaßnahmen im Einzelfall Schäden deutlich reduzieren konnten. Diese Ergebnisse wurden im Weiteren verwendet, um das multi-faktorielle Schadensmodell FLEMOps (Flood Loss Estimation Model for the private sector) abzuleiten (Thieken et al., 2008, Artikel 7). Das Modell schätzt finanzielle Hochwasserschäden an Wohngebäuden und am Hausrat auf Basis von Wasserständen, Gebäudetypen und Gebäudequalität. In einer zusätzlichen Modellstufe (FLEMOps+) können Effekte durch private Vorsorge und Kontamination des Hochwassers berücksichtigt werden.

FLEMOps wurde zunächst für Anwendungen auf der Mikroskala, d.h. für Schadensabschätzungen auf Gebäudeebene, abgeleitet und validiert. Auf der Mesoskala, d.h. für Schadensabschätzungen auf Basis von Landnutzungseinheiten, kann das Modell zusammen mit statistischen Daten, einer Datenbank über Vermögenswerte und Landnutzungsdaten verwendet werden. Bei mesoskaligen Risikoanalysen tritt ein Skalensprung auf zwischen dem Gefährdungsszenario, das meistens rasterbasiert berechnet wird, und Daten über die Exposition, die nur für aggregierte Einheiten, z.B. für Gemeinden, verfügbar sind. Dasymetrische Kartierungsmethoden, die Landnutzungsinformationen als Hilfsvariable verwenden, können diese Lücke schließen. In Thieken et al. (2006a, Artikel 6) wurden bundesweite dasymetrische Karten der Bevölkerungsdichte und des Wohnvermögens auf Basis von CORINE Landnutzungsdaten erstellt. Modellevaluierungen zeigen, dass mit diesen Karten realistische Zahlen über von Hochwasser betroffene Menschen und Vermögenswerte geschätzt werden können.

Um zu beleuchten, welche Modellkomplexität für Hochwasserrisikoanalysen ausreichend ist, wurden mehrere Modellkombinationen für die Gemeinde Eilenburg getestet (Apel et al., submitted, Artikel 8). Drei hydraulische Modelle (d.h. A) eine lineare Interpolation der Pegelwasserstände und Verschneidung mit einem digitalen Höhenmodell, B) das 1D/2D hydraulische Modell LISFLOOD-FP und C) ein vollständiges 2D Hydraulikmodell) wurden mit drei Typen von Schadensmodellen kombiniert (d.h. I) mesoskalige Wasserstands-Schadensfunktionen, II) das mesoskalige Modell FLEMOps+ sowie III) zwei mikroskalige Varianten von FLEMOps+). Reparaturkosten für das Hochwasser 2002 konnten am besten mit LISFLOOD-FP und dem mesoskaligen FLEMOps+ geschätzt werden. Diese Kombination bildet einen guten Kompromiss zwischen Datenanforderungen, Simulationsaufwand und Ergebnisgenauigkeit.

Um Hochwasserschäden in Zukunft zu reduzieren, müssen den Risikoanalysen entsprechende Schutz- und Vorsorgemaßnahmen folgen. Verschiedene Maßnahmen wurden nach dem Augusthochwasser 2002 im Rahmen einer „Lessons Learned"-Studie untersucht. Artikel 9 (Thieken et al., 2004) skizziert die methodische Vorgehensweise sowie einige Ergebnisse über Hochwassergefahrenkarten und Frühwarnung. Vor 2002 bestand ein großer Mangel an Standardisierungen bei der Gestaltung von Hochwassergefahrenkarten, der Berücksichtigung extremer Ereignisse und der Verknüpfung von Gefahrenzonen mit der Raumplanung. Nach dem Hochwasser gab es erste Bemühungen, diese Lücken zu schließen, die nun durch die neue EU-Hochwasserrichtlinie unterstützt werden.

Hochwasserwarnungen fehlten 2002 oft, kamen zu spät oder waren unvollständig, so dass die Betroffenen – vor allem an den Elbzuflüssen - nicht angemessen reagieren konnten. Wie private Haushalte das Hochwasser 2002 (dennoch) bewältigten, wurde von Thieken et al. (2007, Artikel 10) untersucht. Regionale Unterschiede in der Vorsorge, der Reaktion, den Schäden und deren Wiederherstellung konnten vor allem auf Unterschiede in der Hochwassererfahrung und der Hochwassereinwirkung zurückgeführt werden. Wissen über Selbstschutz, Eigentumsverhältnisse und die Größe des betroffenen Haushalts beeinflussten Ausmaß und Art der privaten Vorsorge sowie die Fähigkeit der Betroffenen, Notmaßnahmen effektiv durchzuführen. In Zukunft ist die Bevölkerung besser über Gefahren und angemessenes Verhalten im Ereignisfall zu informieren. Um das Risikobewusstsein zu stärken, sollten Gefahrenkarten öffentlich zugänglich sein. Außerdem sollten Hochwasserwarnungen mehr Informationen über geeignete Schutzmaßnahmen enthalten. Informationsmaterial ist auf bestimmte Bevölkerungsgruppen, wie Mieter, Hausbesitzer, ältere Menschen oder junge Familien, anzupassen.

Neben Versicherungsleistungen spielten staatliche Hilfen und private Spenden 2002 eine wichtige Rolle bei der Schadensregulierung. Daher verglichen Thieken et al. (2006b, Artikel 11) versicherte und nicht versicherte Haushalte. Versicherte Haushalte wurden früher entschädigt. Sie zeigten außerdem ein etwas besseres Risikobewusstsein und Vorsorgeverhalten. Um private Vorsorge in Zukunft zu verbessern, sollte sie mit Anreizen bei der Hochwasserversicherung verbunden werden. Allerdings gibt es Anzeichen dafür, dass Versicherungen wenig unternehmen, um private Vorsorge zu fördern. Daher sind Hochwassergefahren und Vorsorgeoptionen auch den Versicherungen besser zu vermitteln.

Im März 2005 sowie im April 2006 war die Elbe wiederum von Hochwasser betroffen. Obwohl diese Ereignisse deutlich kleiner waren als 2002, ermöglichten sie Kreibich und Thieken (2008, Artikel 12), Änderungen im Hochwasserrisikomanagement und in der Vorsorge in der Stadt Dresden zu untersuchen. Vor dem Augusthochwasser 2002 waren das Hochwasserbewusstsein und die Hochwasservorsorge bei Behörden und Privathaushalten niedrig. Die Umflutrinnen und das Flussbett der Elbe waren nicht gut gepflegt. Nur 13% der Privathaushalte hatten Vorsorgemaßnahmen ergriffen. Nach 2002 wurde ein neues Hochwassermanagementkonzept durch die städtischen Behörden entwickelt, und 67% der Haushalte betrieben Bauvorsorge. Folglich waren die Hochwasserschäden 2005 und 2006 signifikant niedriger.

Es ist eine wichtige Herausforderung für die Zukunft, Schutzmaßnahmen - auch ohne wiederholte Hochwasserereignisse - kontinuierlich zu pflegen und die Vorsorge auf einem hohen Niveau zu halten. Daher sollte sich die Forschung auf folgende Punkte konzentrieren: die Generierung realistischer Hochwasserszenarien für verschiedene Hochwassertypen (z.B. Sturzfluten, Flusshochwasser) unter gegenwärtigen und zukünftigen Klimabedingungen, die Verbesserung der Frühwarnung, die Entwicklung Zielgruppen spezifischer Kommunikation von regional angepassten Vorsorgemaßnahmen sowie die Entwicklung von Instrumenten für die Überwachung des Hochwasserrisikos.

Introduction

Floods are responsible for 20-30% of the economic losses caused by natural hazards worldwide and for more than 50% of all fatalities due to natural disasters (Kron, 2004; Douben and Ratnayake, 2005). Data from the NatCat-Database of Munich Re and from EM-DAT-Database of the Centre for Research on the Epidemiology of Disasters (CRED) reveal that the number of (disastrous) flood events has increased in the last decades. Even death toll due to (freshwater) floods is slightly increasing in the world (Jonkman, 2005). Between 1973 and 2002, almost 9 million people were affected by floods in Europe, and the reported number of floods has increased progressively, especially during the last decade (Hoyois and Guha-Sapir, 2003).

In Germany, almost all big river catchments were affected by severe flooding in the last 20 years (Tab. 1). For example, in the Rhine catchment flooding occurred in 1993 and in 1995, at the river Oder/Odra in 1997, in the Danube catchment in 1999, 2002 and 2005 as well as in the Elbe catchment in 2002 and 2006. Special attention has to be given to the event in August 2002, since it caused financial losses of approximately €11 600 million (Munich Re, 2007) – a figure that by far exceeded losses caused by any other flood event in Germany (Tab. 1). Moreover, 21 people lost their live in Germany due to the august 2002 flood (DKKV, 2003).

Tab. 1: Important flood events and financial losses in Germany (Source: Munich Re, 2007; original values; calculation in Euro with 1 Euro = 1.95583 DM).

Year of the Event	Affected Catchment(s)	Total Loss [Million Euro]
1993	Rhine	530
1995	Rhine	245
1997	Odra	330
1999	Upper Rhine, Danube	410
2002	Elbe, Danube	11 600
2005	Danube	172
2006	Elbe, Danube	125

The events listed in Tab. 1 have initiated a lively debate about floods, their frequencies, their causes and consequences as well as about appropriate mitigation measures (e.g. Bronstert, 1995; Caspary and Bardossy, 1995: Grünewald et al., 1998, 2001; Deutsche Rück, 2000; Grünewald, 2002; von Kirchbach et al., 2002; BMU, 2003a; DKKV, 2003; Jakli, 2003; Mechler and Weichselgartner, 2003; Mudelsee et al., 2003; Kron, 2004; Schwarze and Wagner, 2004; Kundzewicz et al., 2005). Some aspects are:

- Are recent flood events more severe than flooding in the past?
- Are recent floods a signal for or a consequence of climate change?
- What kind of floods can be expected in the future? What can happen as a worst case?
- What are the reasons for increasing flood losses?
- Do we use rivers and their floodplains in the right manner?
- Which measures can effectively and appropriately mitigate or prevent flood losses? How much damage can be avoided by which measure?
- Are current flood warning systems sufficient or how can they be improved?

- Is the safety level of current flood defence schemes sufficient? Which level of safety is safe enough?
- How much public money has to be provided for loss compensation? Is there a need for mandatory flood insurance?

This list already indicates that flood risk research tackles a number of scientific disciplines, is relevant for various stakeholders as well as the public and is not only restricted to natural processes and technical solutions, but has to deal with societal aspects, as well.

In risk sciences, the term risk encompasses the probability and the amount of harmful consequences or expected losses resulting from interactions between natural or human induced hazards and vulnerable conditions (Molak, 1997). As pointed out, e.g. by Merz (2006), flood risks result from a process chain that starts with a rainfall event which triggers runoff processes in the affected catchment areas. Runoff then concentrates in creeks and rivers, where hydraulic processes dominate the further course of the water. If the bankful discharge is exceeded, inundation occurs and exposed elements (i.e. people, buildings or any kind of infrastructure) might be affected. The actual amount of damage depends not only on the severity of the flood event, but also on the use of the floodplains as well as on the coping capacity and the disaster preparedness of the affected society. Thus, flood risk encompasses two aspects: hazard and vulnerability (Mileti, 1999).

Fig. 1 illustrates the distinction of flood hazard, vulnerability and risk. Flood hazard is defined as the exceedance probability of potentially damaging flood situations in a given area and within a specified period of time, while vulnerability addresses the consequences of a flood (Merz and Thieken, 2004).

A common example of a flood hazard statement is the flood frequency curve at a discharge gauge, showing different discharges and their associated exceedance probabilities at one gauging site (e.g. Stedinger et al., 1993). Many uncertainties are, however, attached to flood frequency analysis (see Merz and Thieken, 2005, for a summary). This holds especially if extreme discharges are regarded (e.g. Malamud et al., 2006).

If the consequences of a flood event are to be quantified, hazard statements have to be extended, i.e. they should provide information about the flood intensity, such as spatial pattern of inundation depths or flow velocities (Merz and Thieken, 2004). Such information is achieved by hydraulic modelling. Some methods are described by Bates and de Roo (2000), Rodda (2005) or Büchele et al. (2006).

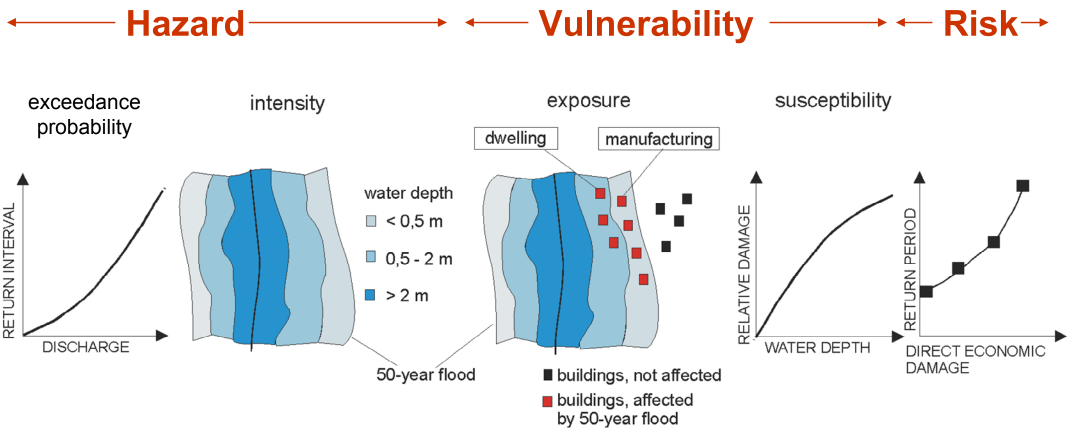

Fig. 1: Flood risk as interaction of hazard (exceedance probability and intensity) and vulnerability (exposure and susceptibility) (Source: Merz and Thieken, 2004).

Flood risk analysis further involves a vulnerability analysis of the elements at risk. The term 'elements at risk' includes all elements of the human system, the built environment and the natural environment that are at risk of flooding in a given area, e.g. population, buildings and civil engineering works, economic activities, ecosystems, etc. (Merz and Thieken, 2004).

There are different concepts of vulnerability and there is no agreed understanding of this term (Blaikie et al., 1994; Comfort et al., 1999; Mileti, 1999; Smith, 2001). For example, Blaikie et al. (1994) analysed the complex socio-economic conditions that create a high degree of vulnerability. Access to resources is often the most critical factor in either achieving a secure livelihood or recovering effectively from disaster. People with access to capital, land, tools and equipment, information, social networks, etc. are the least vulnerable.

In this thesis a narrower definition of vulnerability is used: Vulnerability is composed of two aspects, exposure and (loss) susceptibility (Fig. 1). Exposure analysis answers the question, "Who or what will be affected by floods?" Exposure can be quantified by the total number or the total asset value of all exposed (inundated) elements and is therefore often addressed as damage potential. Analysis of susceptibility answers the question "How and to what extent will the affected elements be damaged?" (Merz and Thieken, 2004; Merz, 2006).

In comparison to other fields in water resources management, damage analysis has not received much attention, and damage or loss data are scarce. Moreover, data analyses revealed that loss data show large scatter (Blong, 2004; Merz et al., 2004). Water depth and building use, the most frequently considered parameters in stage-damage-functions, only explain a part of the data variance (Merz et al., 2004). Therefore, more efforts are needed to improve current loss estimation methods.

Vulnerability and risk analysis can be carried out for all or for only selected elements at risk in the region under study, such as population, residential buildings, critical infrastructure etc. In thesis, vulnerability and risk analyses are in most cases restricted to financial losses at residential buildings.

Risk can be quantified by the expectancy value of the analysed loss indicator within a given period of time (see Merz, 2006 for further details). Typically, risk estimates are based on one year. A comprehensive illustration of risk is given by risk curves (i.e. a graph of frequency versus consequences as drawn in Fig. 1), in which the exceedance probabilities of a number of discrete events and the corresponding amount of loss are shown (e.g. Kaplan and Garrick, 1981). Usually this is a double logarithmic scaled plot.

To reduce flood risk, the analysis and quantification of risk has to be followed by risk reduction measures. If risk is understood as a combination of hazard and vulnerability, a certain risk level can be reduced by decreasing the

- hazard, e.g. by an increase in water retention capacities of the catchment, or
- vulnerability, e.g. by the reduction of the assets in the flood plain (reduction of damage potential/exposure), or by the installation of a flood warning system (reduction of susceptibility) (Merz and Thieken, 2004).

To find, maintain and control appropriate mitigation measures for a given region is the key task of flood risk management. In recent years, there has been a shift from purely technical flood protection to an integrated risk management that involves structural as well as non-structural measures, such as spatial planning, early warning, private precaution, flood insurance, emergency control, etc. (e.g. Takeuchi, 2001; Vis et al., 2003; Johnson et al., 2007).

However, integrated flood risk management is a quite young development and little is known about the efficiency of non-structural measures. For example, Johnson et al. (2007) point out that the policy of involving homeowners in loss mitigation is contrasted by the fact that average losses are on the rise. Therefore, more research is needed on private precaution and self-protective behaviour of exposed residents.

This thesis consists of twelve independent papers dealing with different aspects of flood hazards, vulnerability analyses and risk management in Germany. The papers are grouped into three main sections. The first section deals with the characterisation and modelling of floods in Germany, the second section focuses on new aspects of flood damage analysis and loss modelling, whereas the third section highlights some aspects of flood risk management with a focus on disaster preparedness of private households. In what follows, a short introduction to each of the three main sections is given.

Floods in Germany

The "100-year" flood in the Rhine catchment that occurred in December 1993 was followed only 13 months later, i.e. in January 1995, by a second flood that was similar in magnitude (Fink et al., 1996). Flood discharges at the Odra in July 1997, at the Danube in May 1999 and in August 2005 as well as in the Elbe catchment in August 2002 exceeded the water levels and/or discharges observed so far at many gauges (Grünewald et al., 1998; BfG, 2002; Bayerisches Landesamt für Umwelt, 2006). Therefore, these events initiated discussions about climate change and its likely consequences for river flooding (e.g. Bronstert, 1995; Caspary, 1995; Caspary and Bardossy, 1995; Chbab, 1995; Mudelsee et al., 2003; Kundzewicz et al., 2005). However, up to now there is no clear signal of trends in river flooding (see e.g. Mudelsee et al., 2004 or Svensson et al., 2006 for discussion).

In some areas, the recent flood events motivated researchers to search for historical flood records and to reassess and compare these to the recent events (e.g. Krahe, 1997; Deutsch and Pörtge, 2003; Mudelsee et al., 2004; Pohl, 2004; Grünewald, 2006).

Many flood investigations in Germany have focused on one or a few catchment areas or at single gauging sites (e.g. BfG, 1998; Haupt, 2000; Engel, 2001; Mudelsee et al., 2003; 2004; Böhm and Wetzel, 2006). With regard to the entire area of the country the picture seems to be fragmented. Therefore, discharge data from more than 400 gauging stations distributed all over Germany except for the coastal regions were gathered for the first paper of this thesis (Beurton and Thieken, 2009). Data were analysed with regard to the seasonality of flooding, since seasonality is regarded as an excellent indicator for the investigation of flood causing processes (Blöschl et al., 1999) and is important for many applications in hydrology. Taking the catchment of the river Mulde as an example it is investigated in more detail in Paper 2 (Petrow et al., 2007), how winter and summer floods are connected to general circulation patterns. It is also discussed what this means for flood frequency analysis.

These two papers are aimed at providing a good and general overview of flooding in Germany that cannot be found in the literature so far. They therefore contribute to a better understanding of flood patterns in Germany.

The next two papers (Paper 3 - Thieken and Menzel, 2004; Paper 4 - Apel et al., 2008) address the question how stable and reliable flood hazard assessments are. While Thieken and Menzel (2004) deal with the question of climate change and its possible effects on the flood frequency in some sub-catchments of the German Rhine catchment, Apel et al. (2008) discuss the influence of levee breaches on flood frequency analyses at the Lower Rhine. By both investigations - that are, however, very different in nature – the weaknesses and limitations of commonly used flood frequency analyses are demonstrated. Thieken and Menzel (2004) study whether the mean flood discharge and certain flood quantiles like the 100-year flood discharge change in time and whether these changes can be assessed with certainty or not. Here, a new method for showing the uncertainty of climate change projections that results from the application of a chain of different models is presented, as well.

Apel et al. (2008, Paper 4) extended the probabilistic modelling system that had been developed within the framework of the German Network Natural Disasters (Apel et al., 2004, 2006). The new version is better capable of accounting for retention effects due to dike breaches at a whole river reach. By this, a new approach for the determination of upper bounds of flooding at river reaches with embankments is presented.

Flood losses - analysis and modelling

Besides meteorological, hydrological and hydraulic investigations risk analyses require an estimation of flood impacts, which is normally restricted to adverse effects, i.e. damage and losses. Usually, flood damage is classified into direct and indirect damage. Direct damage occurs due to the physical contact of the flood water with humans, properties or any other objects, while indirect damage is induced by flooding, but occurs - in space or time - outside the actual event (Smith and Ward, 1998). Indirect damage mainly results from an interruption of economic and social activities (Parker et al., 1987). Usually, both types are further classified into tangible and intangible damage, depending on whether or not they can be assessed by monetary values (e.g. Parker et al., 1987; Smith and Ward, 1998; de Bruijn, 2005). In the papers of this thesis monetary flood damage is commonly addressed as flood loss.

For risk analyses and assessment accurate, comparable and consistent data on disaster losses are required for a number of policy issues in order:

- to assess the influences of climate, population growth, land use and policies on trends in losses (Downton et al., 2005),
- to set priorities between competing demands for national and international budget allocations (Guha-Sapir and Below, 2002),
- to evaluate policy successes and failures on the basis of trends and spatial patterns of damage and to think about new policies (insurance, climate policies) (Downton and Pielke, 2005) and finally
- to set priorities about what kind of research to fund as well as to evaluate contributions of science to real-world outcomes (Downton and Pielke, 2005).

In most of the cases, loss data that are aggregated at a regional or national level are sufficient for these purposes. However, very detailed data on specific damaging processes at affected objects are needed for understanding, planning and evaluating disaster risk reduction. Particularly there is a growing demand for flood loss modelling, i.e. the estimation of potential flood losses. Flood loss models are used for a number of issues, such as:

- an evaluation of technical flood defence and alleviation schemes by means of cost-benefit-analyses with the aim to optimise investments (e.g. Resendiz-Carrillo and Lave,

1990; USACE, 1996; Olsen et al., 1998; Al-Futaisi and Stedinger, 1999; Ganoulis, 2003; Penning-Rowsell et al., 2005),
- a comparison of different disaster types (e.g. Jonkman, 2005; Grünthal et al., 2006),
- financial appraisals in the reinsurance industry, e.g., the estimation of probable maximum losses (PML), in order to guarantee solvency (e.g. Kron and Willems, 2002) and
- risk mapping in order to enhance risk awareness (e.g. ICPR, 2001). For example, the new European flood directive demands to determine economic activities that could be affected by floods (EU, 2007).

In order to derive loss models or loss functions, factors and processes that influence flood damage have to be analysed and understood.

This huge demand for loss data is contrasted by the lack or incompleteness of data that have been collected up to now. Only a few data sets are publicly available and little is known about their data quality. A big problem for analyses that are aimed, e.g. at deriving loss functions (stage-damage-functions or depth-damage-functions), is that only a few, if any, explanatory variables such as the water level are available in such data sets. Furthermore, data analyses revealed that loss data show large scatter (Blong, 2004; Merz et al., 2004). Water depth and building use, the most frequently considered parameters in loss functions, only explain a part of the data variance (Merz et al., 2004). If additional information about the affected object, flood warning, precaution etc. is missing, data variability cannot be further explained. Consequently, loss modelling remains insufficiently.

More efforts to collect flood loss data and the development of standardised methods have been constantly called in (e.g. Mileti, 1999; Yeo, 2002; Guha-Sapir and Below, 2002; Handmer et al., 2005; Greenberg et al., 2007). The lack of reliable, consistent and comparable data is seen as a major obstacle for risk analyses and effective and long-term loss prevention (e.g. Changnon, 2003; Downton and Pielke, 2005). To close the current data gap, some detailed surveys were performed at flood-affected residential and commercial properties (e.g. Ramirez et al., 1988; Joy, 1993; Zhai et al., 2005).

An example for a detailed survey of flood losses of private households in Germany is described in this thesis in Paper 5 (Thieken et al., 2005). In the aftermath of the flood in August 2002, 1697 flood-affected private households in Saxony, Saxony-Anhalt and Bavaria were interviewed. Besides the damage to buildings and contents information about a variety of factors that might influence the flood losses were collected. This up-to-date and unique data set was used to quantify how different variables influence flood losses of buildings and household contents (Thieken et al., 2005, Paper 5).

The remaining papers in that section deal with the estimation, i.e. modelling, of flood losses. For flood loss estimation, different input data are required: inundation scenarios, a (relative) loss estimation model as well as an estimation of (potentially exposed) assets. The last aspect is addressed by Kleist et al. (2006). They provide an asset inventory for residential building property in all German municipalities. In Paper 6 (Thieken et al., 2006a) it is demonstrated how these data can be used for large-scale flood loss estimation by applying modern mapping techniques (i.e. dasymetric mapping techniques) in the field of loss modelling and risk analysis.

A new (relative) flood loss model is presented and evaluated in Thieken et al. (2008, Paper 7). The model is based on the empirical data introduced by Thieken et al. (2005, Paper 5). In contrast to stage-damage-curves used hitherto for risk mapping in Germany (e.g. MURL, 2000a; ICPR, 2001), the development of new model was purely based on empirical data and is accomplished by a scaling procedure for applications on the meso-scale. Moreover, model evaluations, which can rarely be found in the literature about loss modelling, were performed. Results are described in Thieken et al. (2008, Paper 7) and Apel et al. (2009, Paper 8).

The papers of that section enhance the current knowledge about flood losses and influencing factors to a great extent. In addition, the presented approaches for model development, scaling and evaluation are new in the field of loss modelling.

The concepts for data collection, analysis, model development, scaling and evaluation that are presented in this thesis for the residential sector have already been successfully transferred to loss data collection and loss modelling in the commercial and industrial sector (Kreibich et al., 2007, submitted; Seifert et al., submitted).

Flood risk management in Germany

In general, disaster or risk management is defined as a systematic management of administrative decisions, organisation, operational skills and abilities to implement policies, strategies and coping capacities of society and communities to lessen the impacts of natural hazards and related environmental and technological disasters (ISDR, 2002).

Often the processes of risk management are described as a cycle that starts with a disastrous event, which is accompanied by certain response activities of the affected society. After the disaster, reconstruction and repair works take place. This phase should be followed by a period of risk analysis and assessment resulting in some effective control measures, which are primarily aimed at preventing and mitigating damage. The concept of the disaster cycle has widely been used by international and national organisations and various versions have been published (e.g. DKKV, 2003; PLANAT, 2004; FEMA, 2004; Kienholz et al., 2004).

In flood risk management, risk reduction often focuses on three aspects: 1) flood abatement with the aim to prevent peak flows, e.g. by an improvement of the water retention capacities in the whole catchment, 2) flood control that is aimed at preventing inundation by structural measures, e.g. embankments or detention areas and 3) flood alleviation with the goal to reduce flood impacts by non-structural measures (Parker, 2000; de Bruijn, 2005). The latter can be further classified into preventive, precautionary and preparative measures. Prevention is aimed at completely avoiding damage in hazard-prone areas, e.g. by flood-adapted land use regulation. Precaution and preparation help to limit and manage adverse effects of a catastrophe and to build up coping capacities by flood-resilient design and construction, development of early warning systems, insurance, awareness campaigns, education, training, putting rescue units on stand-by, etc. (e.g. Vis et al., 2003; DKKV, 2003; PLANAT, 2004; de Bruijn, 2005). In German Water Agencies, these concepts are often addressed as "the three pillars of modern flood risk management" (e.g. BStMLU, 2003, see also DKKV, 2003, for a summary of flood defence concepts in Germany).

Integrated flood risk management is still under development and implementation. Its success might be hampered by a lack of knowledge about the efficiency of different non-structural measures as well as by difficulties in risk communication. Johnson et al. (2007) point out that the policy to account for loss mitigation of exposed residents is contrasted by the fact that average losses are on the rise. For example, potential damage in residential buildings has increased by more than 100% (i.e. 128% to 915% depending on the flood water level and the flood duration) in the UK (Johnson et al., 2007). Therefore, more research is needed to clarify the extent of private precaution and the willingness of residents to prepare for disasters.

Initiated by the German Committee for Disaster Reduction (DKKV) an interdisciplinary „lessons learned"-study was carried out after the Elbe flood in 2002 with the aim to evaluate strengths and weaknesses of the current flood protection and to give recommendations for improved flood mitigation in Germany (DKKV, 2003). The methodological framework and some results in the fields of hazard mapping and early warning are presented in Thieken et al. (2004, Paper 9).

The survey data introduced by Thieken et al. (2005, Paper 5) were further used for a broader analysis of vulnerability and coping capacities of affected private households. The study was performed in order to investigate and to explain regional differences in preparedness, response to early warning, financial losses and recovery (Thieken et al., 2007, Paper 10). Some conclusions about the potential and limitations of private precautionary behaviour should improve current risk management.

As emphasised by Mechler and Wechselgartner (2003) governmental aid and public donations played a crucial role for loss compensation of affected residents and companies in 2002. Therefore, Thieken et al. (2006b, Paper 11) compared recovery, risk awareness and mitigation of insured and uninsured private households. Besides, the insurability of flood losses in Germany and the role of insurance companies in risk management are discussed, as well. While there is a lot of literature about the US national flood insurance program, only little information can be found about flood insurance in Germany. Therefore, Paper 11 contributes new insights to this topic.

In 2005 and in 2006, the Elbe and the Danube were hit again by floods. To further improve the data base of flood losses and to evaluate the results based on data from the event in 2002, a new poll was conducted with a slightly altered questionnaire of the study of Thieken et al. (2005). Although the events in March 2005 and April 2006 were less severe than in August 2002, the new data allowed Kreibich and Thieken (2008, paper 12) to exemplarily study changes in risk management and preparedness in the city of Dresden. Therefore, conclusions about how a flood event can enhance self-protective behaviour and public risk management can be drawn from this analysis.

Despite the huge literature about flood hazard and risk analysis, some aspects have not received much attention by now. These include the analysis of the flood hazard at a large scale (i.e. beyond catchment boundaries), the analysis and modelling of flood losses as well as the contribution of precautionary behaviour of residents at risk to the total risk management. Altogether, the twelve papers of this thesis contribute new results to these topics and thus help to further improve flood risk analysis and management in Germany.

SECTION I:

FLOODS IN GERMANY

Paper 1: Seasonality of floods in Germany

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Abstract

The seasonal distribution of annual maximum floods at 481 gauging stations throughout Germany was analysed and classified by cluster analysis. As a result a new map with three regions that represent homogeneous flood regimes is presented: A) a cluster in the western and central part of Germany with distinct winter floods, B) a cluster with its centre in north and east Germany, in which the percentage of spring and summer floods is higher than in cluster A and C) a small cluster in southern Germany, which is dominated by summer floods. The occurrence of maximum observed flood events in three clusters corresponds well with the general seasonality of flooding. Finally, the stability of the flood regimes in different time periods was analysed, in which a spatial extension of the cluster A towards the south-east was detected. That may hint to changes in westerly circulation patterns, but needs more investigation.

Keywords: flood, Germany, cluster analysis, seasonality, climate change

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1 INTRODUCTION

The increase in dramatic flood events in Germany in the last years – severe flooding occurred in the Rhine catchment in 1993 and 1995, at the Odra in 1997, in the Danube catchment in 1999, 2002 and 2005 as well as in the Elbe catchment in 2002 and 2006 - has initiated a lively debate about climate change and its consequences for river flooding (e.g. Bronstert, 1995; Caspary, 1995; Mudelsee *et al.*, 2003; Kundzewicz *et al.*, 2005; Pinter *et al.*, 2006). Since floods can be caused by different meteorological processes (e.g. convective thunderstorms, cyclones and/or rapid snowmelt) that may dominate during particular seasons, changes in atmospheric conditions may result in changing magnitudes, frequencies or timing of floods. For example, Caspary and Bárdossy (1995) point out the strong linkage of changing atmospheric conditions with the increase in flood events for southwest Germany.

Up to now there is no clear signal of trends in river floods (see e.g. Mudelsee *et al.*, 2004 or Svensson *et al.*, 2006 for discussion). Furthermore, the evaluation of potential hydrologic responses to climate change requires an understanding of the current patterns of flooding at the regional scale (Lins, 1997). Therefore, this paper deals with seasonal patterns of flooding (further called flood regimes) in the whole of Germany as well as their stability during the last 60 years.

The determination of flood seasonality is important for many applications in hydrology. In general, seasonality is regarded as an excellent indicator for the investigation of flood causing processes (Blöschl *et al.*, 1999). It is used in seasonal flood frequency analyses in order to separate floods which were generated by different atmospheric mechanisms (e.g. Ouarda *et al.*, 2000; 2001). Similarity in flood seasonality is particularly used as a classification variable in many regional flood frequency analyses or - more general - for finding and grouping homogeneous hydrological sites in the region under study (e.g. Black, 1994; Black and Werritty 1997; Burn, 1997; Blöschl *et al.*, 1999; Lecce, 2000). Sivapalan *et al.* (2005) point to the strong influence of flood seasonality on flood probabilities. The linkage is explained by direct influence of seasonal atmospheric conditions and by the indirect effect of the seasonality of precipitation and evapotranspiration. Hence, flood seasonality is more than an instrument for regionalisation. It offers information that can be related to the flood probabilities.

Different approaches can be chosen for the derivation of flood seasonality. For example, Lecce (2000) identifies seasonal patterns of flood events in the south-eastern states of the USA by a straight statistical method: Monthly frequencies of flood events, derived from annual maximum series (AMS), were classified by cluster analysis. The cartographic evaluation of the results led to spatial zones of the flood regimes. Cunderlink *et al.* (2004a) warn that this procedure may contain an important part of sampling uncertainty particularly if short records are used. Therefore, Cunderlink *et al.* (2004b) compared directional statistics and relative flood frequencies. In directional statistics each day of the year is represented as a point on a circle. A vector indicates the mean date of flood occurrence (vector direction) and the variance of sample values (vector length) (Burn, 1997). Frequency distributions consist in relative frequencies of flood events that are allotted to defined seasons. Following Cunderlink *et al.* (2004b), frequency distributions give a more detailed view into flood seasonality than directional statistics because they take into account secondary maxima. Furthermore, the explanative power of AMS and POT (peaks-over-threshold) was compared. AMS is easier to generate than POT, but it is less informative referring to flood seasonality

(Cunderlink *et al.*, 2004b). AMS can integrate an annual maximum that does not necessarily result from a flood event. This is critical when an extracted runoff of a dry year is interpreted as a maximum. To reduce the mentioned effects it is recommended to use AMS including observation from periods longer than 30 years (Cunderlink *et al.*, 2004b).

In Germany, many efforts of flood investigation have focussed on one or a few catchment areas (e.g. BFG, 1998; Haupt, 2000; Engel, 2001; Mudelsee *et al.*, 2003; 2004; Böhm and Wetzel, 2006). With regard to the entire area of the country the investigation seems to be spatially fragmented. Therefore, this paper is aimed at completing the debate with regard to the following aspects: First, an intercatchment-based analysis and classification of the seasonality of flooding within almost the entire area of Germany is given. Secondly, important flood events are identified within the different flood regimes. Finally, it is analysed whether the seasonal patterns of flooding have changed in the last decades.

2 STUDY AREA AND AVAILABLE DATA

The study area includes the territory of Germany except for the coastal zones. Germany is influenced by its transitory position between an Atlantic Western Europe and the continental climate in the east. The north-western part is dominated by west-, north-west- and south-west circulation patterns with associated midlatitude cyclone rainfall with a large spatial extension that can cause river flooding (Schmidt, 1950). High pressure systems occur rarely except for spring, and Vb-weather-regimes are infrequent in north-eastern part.

In the very south-eastern part of Germany high pressure situations dominate, especially in autumn and winter. West-, north-west- and south-west circulation patterns are less frequent and occur in a weaker way. Furthermore, Vb-weather regimes are more common in the south-eastern part. This constellation can cause heavy rainfalls, followed by extreme flood events, for example at the rivers Elbe and Odra (Mudelsee *et al.*, 2004). Between the mentioned zones at the north-west and south-east, there is a large transitory territory.

Regime classification has a long tradition in hydrology. For Germany, average runoff regimes were presented among others by Weikof (1885), Keller (1968), Grimm (1968), Marcinek (1976) and BMU (2003). According to the Hydrological Atlas of Germany (BMU, 2003), the major part of Germany is dominated by a pluvial runoff regime. It is partly modified into a nival dominated runoff regime in the highland areas. A particularly high diversification of runoff regimes is identified in the alpine zone in the south of Germany. In this paper, the work on runoff regimes is complemented by an analysis of flood regimes.

The analysis in this paper is based on daily runoff data and focuses on the seasonality of river floods in Germany that means coastal floods are excluded. Furthermore, Lecce (2000) showed that the exclusion of catchment areas smaller than 100 km^2 led to an increase in spatial homogeneity of flood seasonality. Therefore, only gauging stations with a catchment area of more than 100 km^2 were considered. In consequence, flash floods do neither form a part of the study due to their little extension. Additionally, the length of the discharge time series had to top a period of 30 years according to the recommendations of DVWK (1999) and others (e.g. Cunderlink *et al.*, 2004b).

In total, data from 481 gauging stations met all criteria and were further used for the analysis. Figure 1 shows the spatial distribution of the gauging stations classified by the size of their catchment area. Tab. 1 summarises the distribution of their time series length. The temporal beginning and ending of the collected runoff data vary. The core period lies between 1970 and 2000. More than a half of the gauges include data from less than 50 years, only a third contains between 51 and 75 years (Tab. 1).

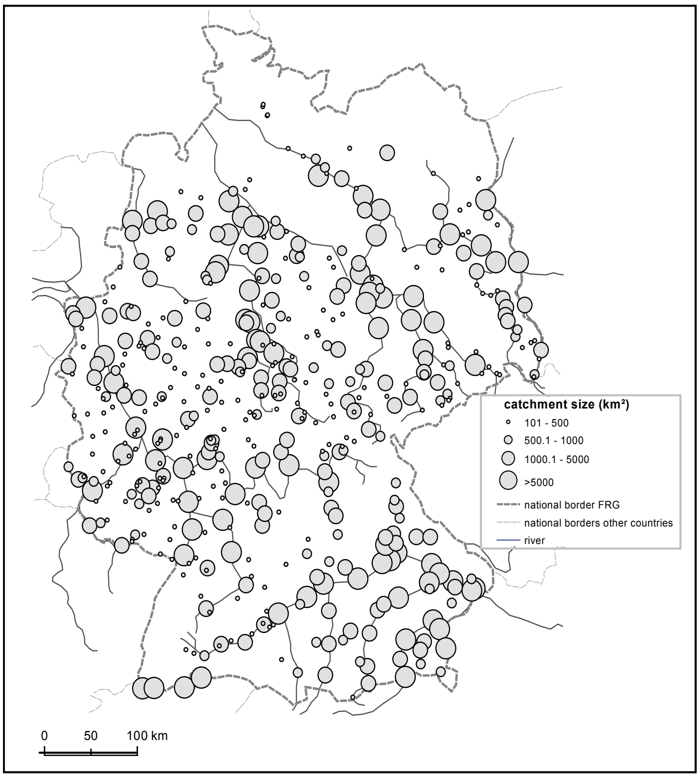

Fig. 1: Distribution of the 481 gauging stations classified by the size of their catchment area.

Tab. 1: Distribution of time lengths within the collected data.

Length of discharge time series	Number of gauges
30 - 50 years	247
51 – 75 years	153
76 – 100 years	65
> 100 years	16

3 REGIONALISATION METHOD

The procedure of the data analysis was basically aligned with the approach of Lecce (2000), but was complemented by an analysis of the maximum observed floods as well as a dynamic analysis of the spatial pattern of flood seasonality. Initially, AMS were extracted from the daily runoff data of each gauging station taking into account hydrological years from 1st November to 31st October. According to the recommendations of DVWK (1999) it was tested whether annual maxima of consecutive years were independent, i.e. two discharge maxima had to occur with a temporal distance of more than seven days, otherwise the lower value was substituted. In the following step, frequency distributions were generated, which represent the percentage of floods that occurred each month at a particular gauging station. The analysis was performed by Matlab tools.

Subsequently, the frequency distributions were classified by cluster analysis with SPSS. To enable the analysis of such a large data set, a k-means-algorithm was chosen. The k-means-algorithm is a non-hierarchical partitioning clustering method, i.e. the cluster centres are iteratively calculated until a convergence criterion is met. In SPSS, the initial configuration of a given number of cluster centres *k* is based on the first *k* gauges in the data set. All other gauges are then classified to the centres on the basis of the Euclidian Distance between the respective monthly frequencies. Then, the cluster centres are recalculated and the classification is reiterated until the final configuration is reached.

The overall aim of clustering is to minimise the within-cluster variance and maximise the between-cluster variance (e.g. Kaufman and Rousseeuw, 1990). However, the number of clusters *k* is not known a priori and constitutes a core problem of partitioning clustering methods. There are no fixed rules to define the number of clusters; every decision will be just an approximation to the "true" number of the structure of clusters in the data. To figure out the optimal number of clusters in this study thematic, cartographic and statistic criteria were combined. Firstly, the k-means algorithm was tested for 29 variants ranging from 2 to 30 clusters. The maximum of 30 clusters was inspired by the results of the runoff regime analysis presented by the Hydrological Atlas of Germany (BMU, 2003), where approximately 30 zones with different runoff regimes were identified. The statistic results were then visualised in ArcGIS and evaluated with regard to an informative and reasonable cartographic representation. The selected cluster variant was then interpreted and mapped.

The calculation of the seasonal frequency distributions as well as the cluster analysis was performed for varying time frames. The first calculation included all 481 AMS data independently from the fact that they do not exactly refer to the same period. The results of this analysis formed the basis for the general classification of flood regimes in Germany. Secondly, an analysis with the aim to identify the dynamics of the seasonal flood pattern was performed. For this, monthly flood frequencies were determined on the basis of AMS data covering the period from 1971 to 2000 only. Subsequently, the k-means clustering was applied to this data subset. The selection of this time frame was motivated by the findings of Caspary and Bardossy (1995), who detected a changing frequency of atmospheric circulation patterns (west cyclonic) and an increase in extreme winter floods in the 1970ies. Moreover, the data density was the highest in this period.

In further calculations, frequencies and clusters were determined in a moving 30-year window starting in 1941. In all three time periods (i.e. 1941-1970, 1951-1980 and 1961-1990) the k-means cluster algorithm was used to assign each gauge to a-priori fixed cluster centres in order to ensure a consistent interpretability of the clusters. For this, the cluster centres of the analysis in the period 1971-2000 were used.

4 RESULTS AND DISCUSSION

4.1 Flooding and catchment size

To get an idea whether flood seasonality depends on the catchment size although small catchments (<100 km^2) had been omitted from the analysis, the relationship between the size of the catchment area and the percentage of floods per season is shown in Figure 2. The seasons in this study were defined as:

- winter: December to February,
- spring: March to May,
- summer: June to August, and
- autumn: September to November.

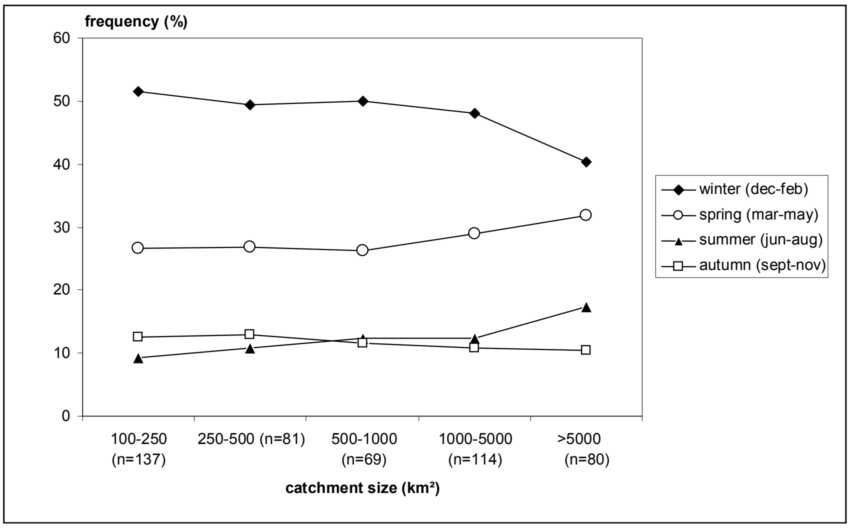

Fig 2: Relation between catchment area and seasonal flood occurrence in the whole data set (n = 481).

Figure 2 demonstrates that all catchments are dominated by winter and spring floods. Within catchments larger than 500 km² the importance of summer floods increases lightly. Within catchment areas of more than 5000 km² winter flood events are less numerous. Except for large catchments there seems to be no notable change in the seasonal distribution of flooding with increasing catchment size within the analysed data set. However, the results are influenced by the spatial distribution of the data. In the south of Germany there are very few gauging stations smaller than 500 km² (Fig. 1). Therefore, the whole data set was further used for flood regime classification.

4.2 Reasonable number of clusters

The cartographical visualisation of the 29 cluster variants confirmed the existence of spatial patterns of flood seasonality within the study area. However, variants with a low number of clusters revealed more compact, spatially coherent and clear patterns than those with a higher number of clusters. With an increasing number of clusters, the numeral distribution of the objects (i.e. gauging stations) within the clusters got more and more unbalanced, i.e. variants with more than four clusters contained outlier clusters with extremely few (i.e. one to two) objects. For example, the 2-cluster solution integrates 73% of the objects in one cluster and the rest of 27% in the second. In contrast, the 5-cluster solution already contains three clusters covering 51%, 38%, and 10% of the objects and two clusters with small shares of 0.8% and 0.2%, respectively. Therefore, a solution with few clusters seems to be favourable for interpretation and visualisation.

To prove the quality of the different cluster solutions, the total within-cluster variance was calculated and plotted against the number of clusters (Fig. 3). In general, the variance is decreasing with an increasing number of clusters, except for the 5-cluster solution. To further evaluate the trend of the within-cluster variance, the percental amelioration of the variance with regard to the preceding cluster solution was determined. Fig. 4 images the results. The most striking points are the high reduction of the within-cluster variance of the 3-, 4- and 6-cluster solution (marked by bold numbers in Fig. 4). However, the strong positive value of the 6-cluster solution results from the high decrease in the within-cluster variance of the preceding 5-cluster solution. Among all presented cluster solutions the 3-cluster variant shows the highest reduction of variance and was thus selected for further examination. It offered the best conditions for cartographic mapping and reasonable interpretation.

4.3 Flood regimes in Germany

In what follows, the 3-cluster solution is described and interpreted in detail.

Spatial pattern Fig. 5 shows the spatial pattern of the 3-cluster solution as well as the monthly frequencies of flooding per cluster. The latter are given as the mean of the frequency distributions of all gauges within the corresponding cluster and therefore represent the cluster centres. The clusters divide the study area into a western, an eastern and a southern part with pronounced differences in the seasonal distribution of flooding. On the western territory of Germany the flood regime *A* is located. Its north-south extension spans from the Upper Rhine to the middle part of the river Ems. Towards the east it is limited by a wide arc touching the zone of the Thuringian/Franconian Slate Mountains. To the east of the mentioned flood regime, there is the spatially diffuse cluster *B*, which is extended to the eastern border of Germany. The gauging stations corresponding to this cluster also penetrate the zone of cluster *A*. In contrast, in the southern area of Germany a well-defined cluster *C* is identified. It covers the complete territory of the southern part of the Danube catchment.

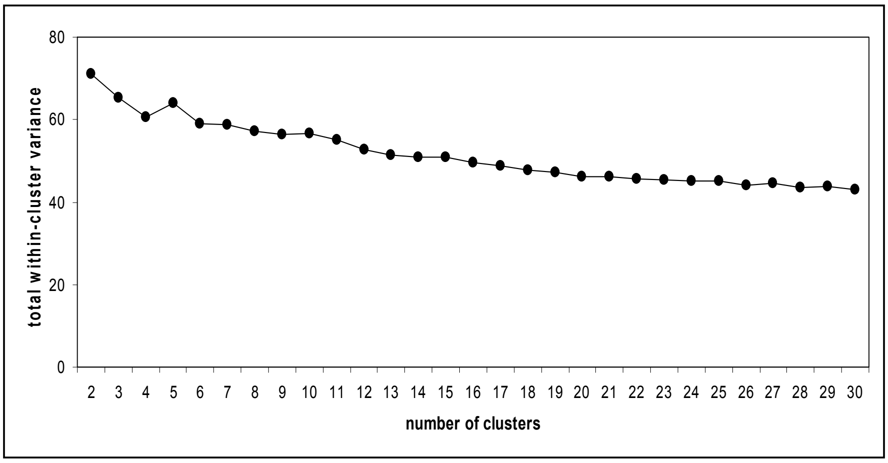

Fig. 3: Total within-cluster variance versus number of clusters (whole data set; n = 481).

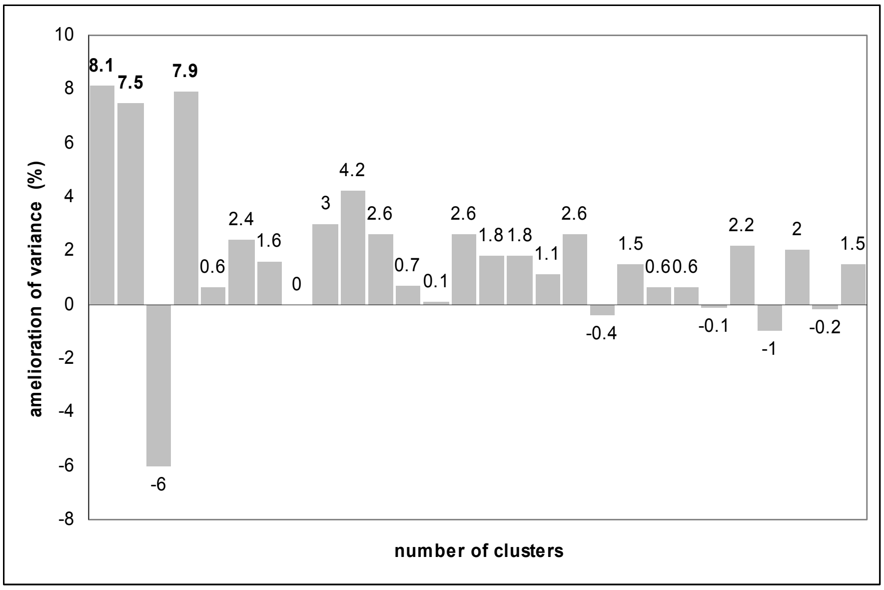

Fig. 4: Percental amelioration of variance with regard to the preceding cluster solution.

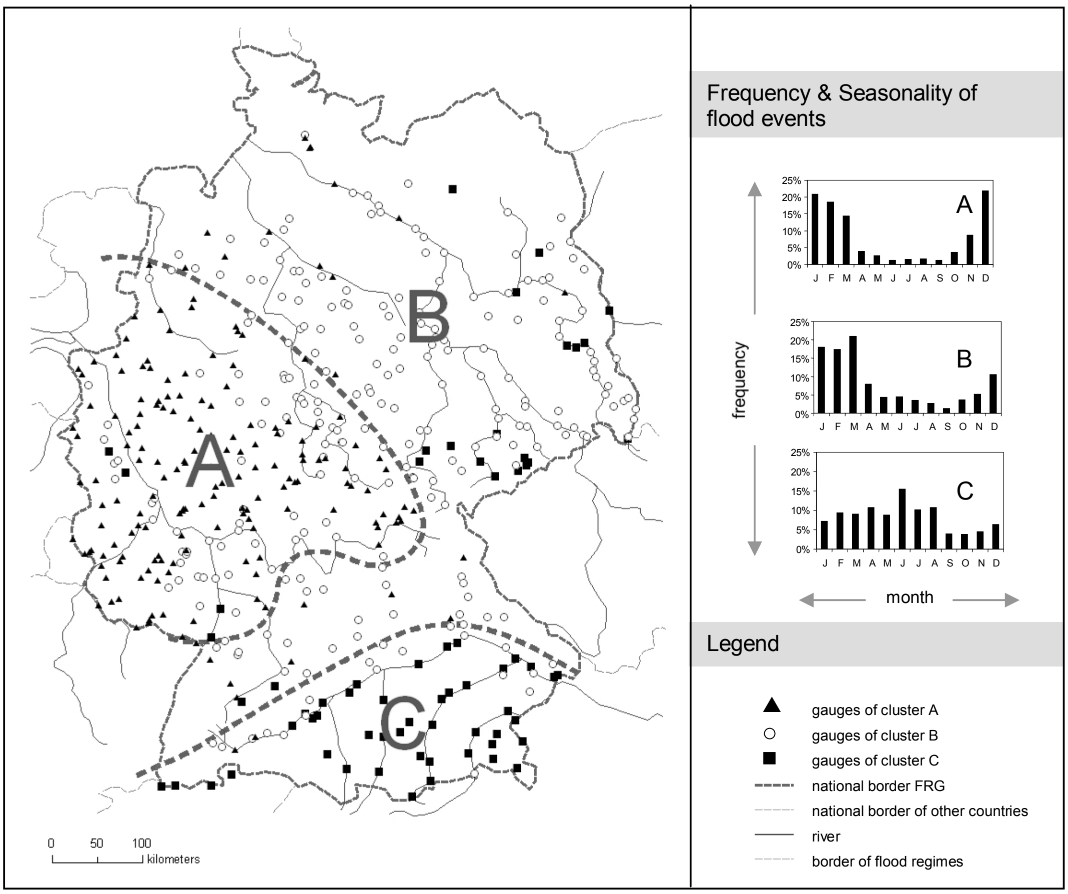

Fig. 5: Spatial pattern of the 3-cluster solution and its cluster centres on the basis of the whole data set (n = 481).

Tab. 2: Percentage of annual maximum floods per season in the three flood regimes shown in Fig. 5 and Fig. 7.

	Cluster/Flood regime (all data; Fig. 5)			Cluster/Flood regime (data from 1971-2000; Fig. 7)		
	A	B	C	A	B	C
Percentage winter floods	61%	46%	23%	57%	41%	25%
Percentage spring floods	21%	33%	29%	24%	38%	31%
Percentage summer floods	4%	11%	36%	6%	12%	31%
Percentage autumn floods	14%	10%	12%	13%	9%	13%

Seasonality within the identified clusters The seasonal distribution of floods is summarised in Tab. 2. It shows that cluster *A* is dominated by winter floods (61%). December is the most important month for flooding with a maximum share of 22% of all flood events (Fig. 5). In spring, 21% of the floods occur, from which 14% fall upon March. The summer is the least important season for flooding (Tab. 2).

The concentration of flood events during the winter months is related to west wind dynamics and to the influence of the Atlantic climate. They determine the thermal characteristics and the availability of water within the region of cluster *A*. The temperature rarely falls below the freezing point and winterly precipitation maxima shape directly the runoff distribution. Cluster *A* constitutes a thermal and dynamic homogeneous region.

During summer the portion of flood events decreases because of the strong influence of the vegetation coverage and evaporation.

Cluster *B* is characterised by pronounced spring and winter floods (Tab. 2). In comparison to cluster *A* the December maximum is shifted to March, where 21% of all flood events occur (Fig. 5). But still winter is the most important season for flooding with a total share of 46% (Tab. 2). Summer floods are represented by 11% and thus more frequent than in cluster *A*. Autumn floods show a similar low frequency. In fact, September is the month with the lowest percentage of flood events (Fig. 5).

Cluster *B* integrates a huge amount of different catchment areas from the south-west to the north-east of Germany. Any interpretation has to be seen as a general approach and should be verified in further studies. In general, the seasonal characteristics of flood regime *B* are similar to the constitution of the winter dominated flood regime *A*. However, summer and spring floods are more pronounced than in the western part of Germany. The shift of the maximum of flood events in winter (flood regime *A*) to spring (flood regime *B*) has to be explained by the growing continental influence towards the east. The increasing annual temperature amplitude leads to longer snow retention and retards consequently the availability of melt water. Melt water that comes from the High Sudeten Mountains and feeds for example the Elbe River is retained until March or even May (Liedtke and Marcinek, 1994). However, continental and Atlantic influences on the atmospheric conditions change irregularly during the year (LUA SA, 2003). Winter floods result from west wind dynamics which lead to mild climate and defrosting conditions. For example, this was shown for flooding in the Mulde catchment by Petrow *et al.* (2007). The identified slight increase in summer floods within cluster *B* is related to intense summer rainfall, which often is linked with Vb-weather conditions (BFG, 1998; Mudelsee *et al.*, 2004; Petrow *et al.*, 2007). Summer floods like at the Elbe River in August 2002 were initiated by intense summer rain that results from such weather conditions (Ulbrich *et al.*, 2003).

Except for a small area in the *Erzgebirge* and the Spree catchment, the southern cluster *C* covers the area of the German Alps and Pre-Alps and is limited in the North by the river Danube. In contrast to the clusters *A* and *B*, it describes a summer flood regime, i.e. 36% of the floods occur in summer, from which 15% appear in June (Tab. 2, Fig. 5). Spring is also an important flooding season with a portion of 29% of the annual flood events, while the frequency of winter floods dropped to 23%. Again, autumn is the least important season for flooding (Tab. 2).

To understand the constitution of the flood regime *C*, it is useful to look at the flood runoff conditions of the river Danube and its tributaries. All rivers feeding the Danube from the right hand side originate from the north-eastern Alps. The largest one is the river Inn with a catchment area of 26096 km^2. Its runoff characteristics are formed by catchments in the High Alps including glacier planes of about 720 km^2. The thermal conditions of the high mountains and their foreland cause long lasting snow retention. Corresponding to a long period below the freezing point, melt water is not available before spring or even summer. During these seasons low pressure systems towards north lead to more frequent flood events (Liedtke and Marcinek, 1994). The rivers Iller, Lech and Isar are also important for the characteristics of the flood regime *C*. Strongly influenced by the climate conditions in the area of the Alpine foreland and Northern Alps, the key moments in their flood seasonality are the melting periods. Further, convective rainfall of high intensity might influence the high percentage of summer flooding (see also Böhm and Wetzel, 2006).

4.4 Maximum observed floods

To further characterise the flood regimes, the maximum observed floods (MOF) are analysed in this section. For this, the MOF at each gauge was determined firstly for the whole observation period and secondly in the period 1941-2000 only. Fig. 6 shows the absolute number of gauges with a MOF per decade as well as its relation to the number of available data in that decade. Most of the MOF were observed in the decade 1991-2000. The fraction of gauges with a MOF is, however, similar in three decades: 1941-1950, 1981-1990 and 1991-2000. In the meantime, i.e. from 1951 to 1980, considerably less MOF were noticed per decade (Fig. 6). This might hint to long-term (multi-)decadal fluctuations of river discharges that have recently been discovered, for example, by Labat (2008) in very long time series.

When the MOF is combined with the 3-cluster solution shown in Fig. 5, then it reveals that most gauges in flood regime *A* experienced a MOF in the decade 1961-1970 (16% of the gauges), 1981-1990 (27%) and 1991-2000 (30%). The MOF can be attributed to severe winter floods in the Rhine catchment in December 1993, January 1995, February 1970, 1984 and 1946 (Tab. 3). Thus, the seasonality of severe flooding corresponds well with the overall flood regime.

In flood regime *B* a MOF was detected at more than 50% of gauges between 1981 and 2004. Here, important flood events happened in February 1946 in the catchments of the rivers Weser and Ems, in August 2002 in Elbe catchment as well as in April 1994, March 1988, January 2003 and May 1978 (Tab. 3). This selection already demonstrates that the seasonality of flooding – even of severe events - is more heterogeneous than in flood regime *A* (see also Fig. 5).

In flood regime *C* a MOF was observed at one third of the gauges in the 1990s. At another 19% of the gauges a MOF was detected in the 1950s and at 12% in the current decade. Only three events were particularly important in this cluster, namely flooding in May 1999, July 1954 and August 2002 (Tab. 3). Again, the seasonality of the MOF corresponds well with the overall flood regime *C*.

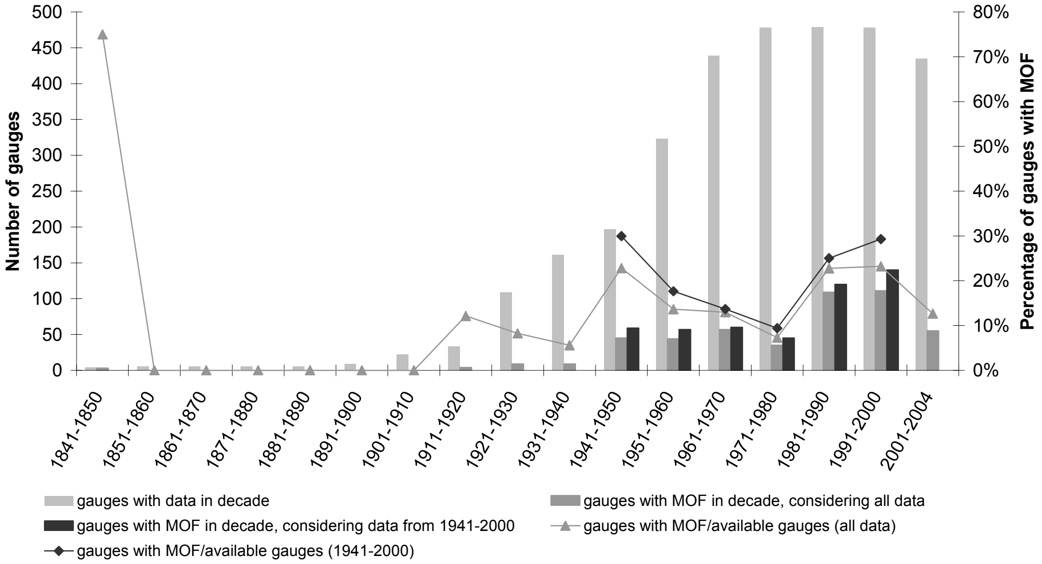

Fig. 6: Number and percentage of gauges with maximum observed flood (MOF) per decade.

Tab. 3: Events at which the maximum flood discharge (MOF) was detected at ten or more gauges.

EVENT (Year/Month)	Number of gauges in Cluster A	Cluster B	Cluster C	Sum of gauges	Share from total (n = 481)	Cumulative percentage (n = 481)
1946/02	10	18	0	28	5.8%	5.8%
1993/12	19	8	0	27	5.6%	11.4%
2002/08	0	18	7	25	5.2%	16.6%
1970/02	14	9	0	23	4.8%	21.4%
1995/01	18	4	0	22	4.6%	26.0%
1999/05	0	0	20	20	4.2%	30.1%
1954/07	0	9	10	19	4.0%	34.1%
2003/01	6	11	0	17	3.5%	37.6%
1988/03	3	12	1	16	3.3%	41.0%
1994/04	2	14	0	16	3.3%	44.3%
1981/03	7	7	0	14	2.9%	47.2%
1984/02	14	0	0	14	2.9%	50.1%
1978/05	2	11	0	13	2.7%	52.8%
1981/08	8	3	0	11	2.3%	55.1%
1960/12	9	1	0	10	2.1%	57.2%
1981/07	0	9	1	10	2.1%	59.3%
1998/10	7	3	0	10	2.1%	61.3%

4.5 Dynamics of the flood regimes

In this section, it is analysed whether the three flood regimes can also be found in four 30-year time windows ranging between 1941 and 2000. Data availability is presented in Tab. 4. Since the data coverage was at best in the period 1971-2000, this was chosen as reference, i.e. a 3-cluster solution was derived for this subset and was further used to classify the data from the other time periods.

In general, all three flood regimes that were identified in the whole data set (Fig. 5) can also be found in 1971-2000. However, the cluster centres as well as the spatial pattern of the clusters have changed a little (Tab. 2, Fig. 7). In comparison to the clusters from whole data set, the clusters in 1971-2000 are spatially more coherent. Especially, the flood regimes *A* and *B* are separated more clearly (compare Fig. 5 and Fig. 7). In the period 1971-2000, the flood regime *A* also covers the northern part of the Danube catchment, while the flood regime *B* is almost restricted to the northern und eastern part of Germany and is characterised by more pronounced flooding in spring, particularly in March (Fig. 7, Tab. 2). Cluster *C* alters only slightly in space as well as in character (Fig.5, Fig. 7, Tab. 2).

The 3-cluster solution of the reference period was subsequently used to classify the monthly frequencies of annual maximum floods in three other 30-year time periods. The number and percentage of gauges per flood regime is summarised in Tab. 4, changes in the spatial pattern are shown in Fig. 8. In the period 1961-1990 there is only little change, which mainly concerns the portion of flood regime *B* and *C* (Tab. 4). In comparison to the reference period the flood regime *C* is more present in the eastern part of Germany (e.g. in the *Erzgebirge*, see Fig. 8). This effect is even more existent in the period 1951-1980.

Another change can be detected in the period 1941-1970. Here, the percentages of gauges that belong to flood regime *A* is remarkable lower than in the other periods in favour of flood regime *B* (Tab. 4). Fig. 8 shows that in this time period the flood regime *B* with remarkable flooding in spring spreads towards the southern part of the country and penetrates the regimes *A* and *C*. Thus, this analysis might give some, but weak evidence that flooding in spring due to snow melt is becoming less important, while flooding in winter has recently increased and is becoming dominant for the central and south-western parts of Germany.

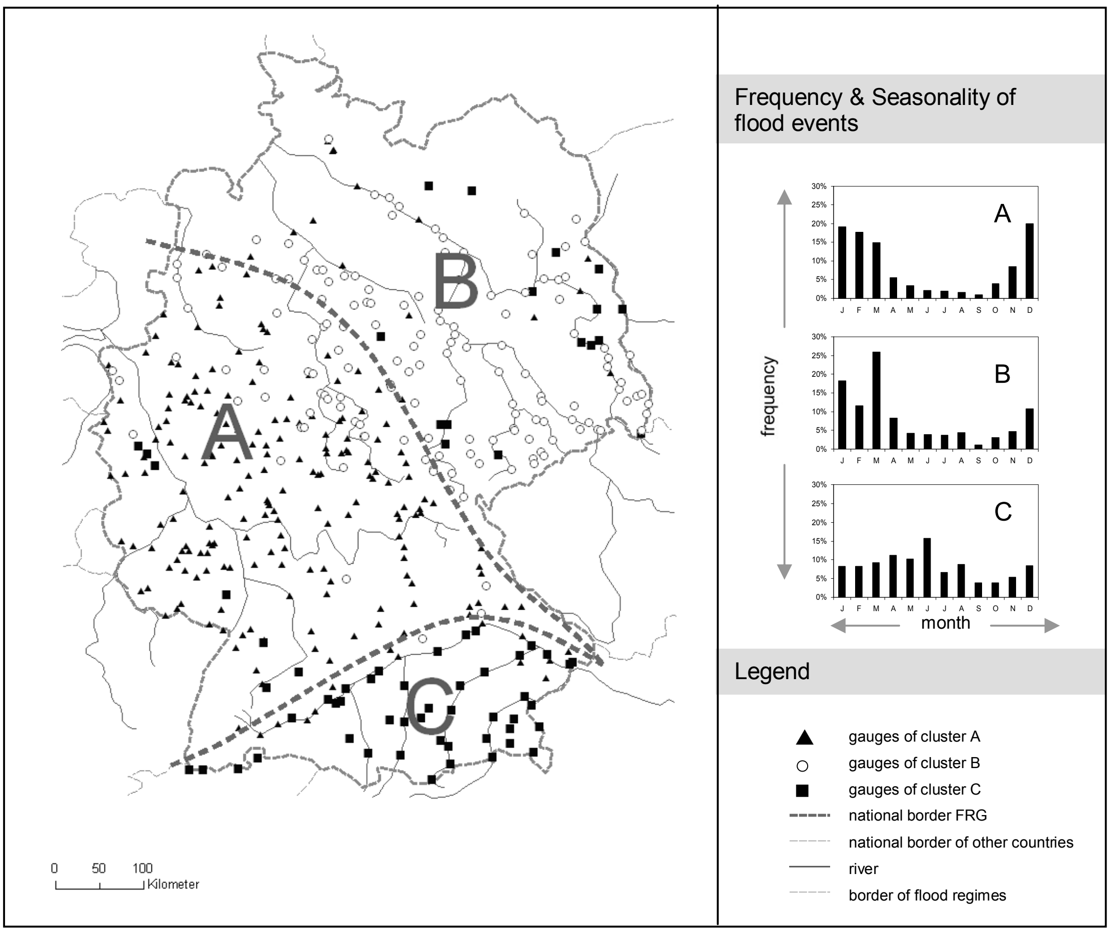

Fig. 7: Spatial pattern of the 3-cluster solution and its cluster centres on the basis of the data from 1971 to 2000 (n = 422).

Tab. 4: Number and percentage of gauges in the three flood regimes in different time periods.

Time period	Available gauges	Number of gauges in cluster/flood regime			Percentage of gauges in cluster/flood regime		
		A	B	C	A	B	C
1971-2000	422	209	146	67	49%	35%	16%
1961-1990	343	173	89	81	50%	26%	24%
1951-1980	222	100	57	65	45%	26%	29%
1941-1970	165	52	76	37	32%	46%	22%

5 CONCLUSIONS

By combining a quantitative approach in terms of cluster analysis of monthly flood frequencies with a qualitative evaluation of the spatial pattern, three flood regimes were identified and interpreted in Germany. However, the definition of the appropriate number of clusters or flood regimes was difficult. The spatial distribution of clusters demonstrated highly diffuse and overlaying patterns when more than four clusters were chosen due to outliers containing extremely few samples. The relationship between the catchment size heterogeneity of the data set within each cluster and its spatially diffuse pattern did not lead to a specific linkage. Therefore, further studies are needed to clarify this point.

Nevertheless, the 3-cluster solution revealed a reasonable pattern of flood regimes. Winter floods are predominant in regions in the west and north-west of Germany, which are influenced by the Atlantic. They originate mostly from rainfall and mirror the impact of westerly circulation patterns. Towards the east pluvio-nival spring and winter floods become more frequent. This reflects the influence of westerly circulation patterns, topologically higher altitudes and its position within the path of Vb-circulation patterns. Southwards a pluvio-nival dominated summer flood regime is identified. It is predominantly influenced by Alpine tributaries. The flood regimes are consistent with the extent and the timing of events that caused maximum observed floods at gauges that belong to the clusters.

Comparing the results with a traditional classification of runoff regimes (Grimm, 1968) parallels can be drawn at the large scale with regard to the spatial and temporal distribution of flood events. The differentiation of the area due to increasing continentality towards the east and increasing topological altitude towards south is similar in both studies. Therefore, the partial transfer of the type of feeding from Grimm’s runoff regimes to the identified flood regimes is legitimated.

The analysis of the stability of the flood regimes during the last 60 years revealed that slight changes occurred depending on the chosen time span for analysis. For example, in the period 1971-2000 the flood regimes were spatially more coherent than in the general analysis. There are weak hints on shifts towards increased flooding in winter and in spring. However, for more profound conclusion long-term fluctuations should also be investigated.

To sum up, the applied method gave an adequate base for the intentioned overview of flood regimes in Germany. The analysed core variable “seasonality” ensures the integration of the interacting flood producing factors, such as atmospheric circulation and specific hydrological response. If it is intended to highlight sub-regimes on a meso- and micro-scale, the data set should be reduced concerning geographical similarities and proximity. This step can base on the regionalisation that was developed in this study.

Acknowledgements

Data provision from various water authorities in Germany is gratefully acknowledged.

References can be found at the end of the thesis.

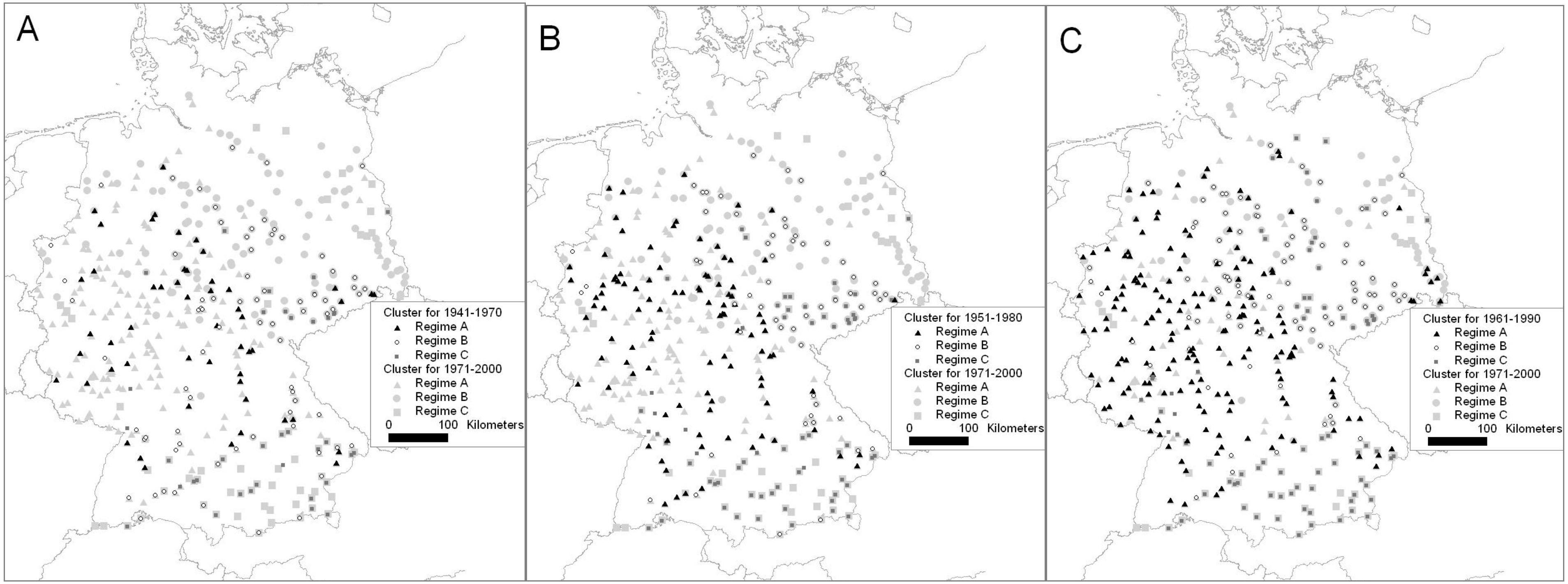

Fig. 8: Spatial patterns of the three flood regimes in different time periods. A: 1941-1970, B: 1951-1980 and C: 1961-1990.

Paper 2: Aspects of seasonality and flood generating circulation patterns in a mountainous catchment in south-eastern Germany

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Abstract

Analyses of discharge series, precipitation fields and flood producing atmospheric circulation patterns reveal that two governing flood regimes exist in the Mulde catchment in south-eastern Germany: frequent floods during the winter and less frequent but sometimes extreme floods during the summer. Differences in the statistical parameters of the discharge data can be found within the catchment from west to east. The discharges are compared to a number of landscape parameters that influence the discharge in the sub-catchments. Triggering circulation patterns were assigned to all events of the annual maximum discharge series in order to evaluate which circulation patterns are likely to produce large floods. It can be shown that the cyclone Vb-weather regime (TM, TRM) generates the most extreme flood events in the Mulde catchment, whereas westerly winds produce frequently small floods. The Vb-weather pattern is a very slowly moving low pressure field over the Gulf of Genoa, which can bring large amounts of rainfall to the study area. It could also be shown that even with the two flood regimes estimates with the annual maximum series provide a safer flood protection with a larger safety margin than using summer maximum discharge series for extreme summer floods only. In view of climate change it is necessary to integrate knowledge about catchment characteristics, the prevailing flood regime or the trends of weather patterns in the estimation of extreme events.

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1 INTRODUCTION

Limited data on extreme and thus rare flood events complicate the accurate estimation of design discharges (e.g. Francés, 2001; Benito et al., 2004; Merz and Thieken, 2005). Numerous approaches have been developed for flood estimation, which include statistical approaches such as flood frequency analysis (FFA), the use of envelope curves as well as rainfall-runoff modelling with hydrological models. The focus in this study is set on the FFA.

The most common methods for FFA use annual maximum series (AMS) and peak over threshold series (POT) (Institute of Hydrology, 1999). The AMS and POT series can also be extracted for summer or winter seasons, when, for instance, one flood process type (e.g. floods triggered by snow melting) is of special interest. Several distribution functions such as the Gumbel, Weibull, Generalised Extreme Value, or the Pearson type III can be fitted to the data (Hosking and Wallis, 1997; Institute of Hydrology, 1999). Although these functions and possibilities exist as to which data to integrate, large uncertainties still remain when estimating extreme events.

There is much debate about the length of the data series. Short series may not capture the entire flood variability and very long series may not reflect stationary conditions (e.g. Bárdossy and Pakosch, 2005; Khaliq et al., 2006). Moreover, it is questionable whether or not an AMS is stationary when the discharges reflect different flood producing processes. Independence, homogeneity and stationarity are required characteristics of the data to legitimate flood frequency analysis (Stedinger, 2000; Kundzewicz and Robson, 2004). However, often these criteria are not satisfied due to climatic change and/or anthropogenic influence (Webb and Betancourt, 1992; Kleměs, 1993; Jain and Lall, 2000; Sivapalan et al. 2005; Svenson et al. 2005; Khaliq et al., 2006).

Independence is almost always given, when analysing annual maximum series, whereas partial series have to be carefully examined in order to avoid miscounting one flood event as two. Usually, a threshold of several days is included in the extraction of the data, which defines the minimal time between two floods to ensure independence of the events. This threshold can comprise up to 30 days depending on the catchment area and discharge conditions. Stationary conditions seldom exist due to changes in climate, land use or in the vulnerability of the study area, although these are often assumed (Merz, 2006). Moreover, the dynamics of atmospheric processes and flood generation have to be taken into account in the study of stationarity and independence and further in the FFA (Merz and Blöschl, 2003; Sivapalan et al. 2005).

The relationship between climate and flood generation has been of growing interest and study (Webb and Betancourt, 1992; Kästner, 1997; Jain and Lall, 2000; Bárdossy and Filiz, 2005; Steinbrich et al., 2005; St. George, 2007). Steinbrich et al. (2005) analyse the correlation between circulation patterns (CP) and heavy rain for the south-western part of Germany (Baden-Wuerttemberg). Kästner (1997) found that only five out of thirty different weather patterns are susceptible to produce flood events in Bavaria. Three catchments in southern Germany (Bavaria), which have different discharge characteristics and are differently influenced by snow melting, were studied. Kästner (1997) found the Vb-weather regime to be most susceptible for the generation of large floods. This weather system is a low pressure system that moves very slowly from the Gulf of Genoa northwards. It can accumulate large amounts of moist and warm air over the Mediterranean Sea, which is transformed into large precipitation amounts that fall along the northern slopes of the Alps and mountain ranges in

Central and Eastern Europe. It is therefore interesting to analyse the relationship of circulation patterns and flood generation in the study area.

More information about flood generating processes can be gained when extending the study from one gauge station to the hydrological behaviour of sub-catchments and neighbouring regions (Harlin and Kung, 1992; Merz et al., 2006; Ouarda et al., 2006). Harlin and Kung (1992) extract for each sub-catchment the most extreme measured events and simulate the simultaneous occurrence of the floods which has not been observed yet. Of special interest for the flood hazard estimation of ungauged areas is also the regional FFA which incorporates flood process information from neighbouring catchments (e.g. Stedinger, 1983; Hosking and Wallis, 1997; Institute of Hydrology, 1999). Regionally valid distribution functions are fitted to data of preferably independent gauges within a region, which exhibit, in general, better fits (Merz, 2006).

In this paper the flood discharge characteristics of the Mulde catchment in south-eastern Germany are analysed according to stationarity, their spatial distribution of the statistical moments and the relationship between landscape characteristics and flood peaks. Additionally, the relationship between the dominating weather pattern in Europe and the flood generation in this catchment is discussed. The following questions will be answered based on this analysis: Which landscape components (geology, soil, groundwater flow, land use, precipitation) contribute to the flood discharge regime? Can seasonal or spatial differences be distinguished? Do specific circulation patterns exist which trigger large events? And finally, are the requirements for the flood frequency analysis with AMS for this catchment fulfilled?

2 STUDY AREA AND DATA

2.1 Study area

The Mulde catchment is a sub-catchment of the Elbe River basin in south-eastern Germany. The southern boundary is marked by the mountain ranges of the Erzgebirge, which coincides with the Czech – German border. The catchment has a total area of 6171 km² (at the gauge Bad Düben) and has three large sub-catchments (Zwickauer Mulde, Zschopau, Freiberger Mulde), which drain the upper, mountainous part of the catchment (Fig.1). Within only 20 kilometers, the tributaries Zschopau and Freiberger Mulde disembogue near the gauge Erlln (gauge 13, Fig. 1) into the Zwickauer Mulde and form the Vereinigte Mulde ("Joined Mulde"), which disembogues near the city of Dessau into the Elbe River. ′

The elevation ranges from 52 m to 1213 m asl. with approx. 2/3 of the area being lowlands and 1/3 mountains (500 – 1213 m asl) (Fig. 1). The mountain ranges in the south cause fast runoff responses to rainfall events in the tributaries, whereas in the major part of the catchment slower runoff responses dominate. The annual precipitation ranges from 500 mm in the lowlands to 1100 mm in the mountain ranges.

The landscape characteristics of the catchment such as geology, soil, hydro-geology and land use parameters were evaluated to gain information about the variability of the discharge behaviour. Therefore, the catchment was split into three zones, which correspond to the three large sub-catchments (Fig.1).

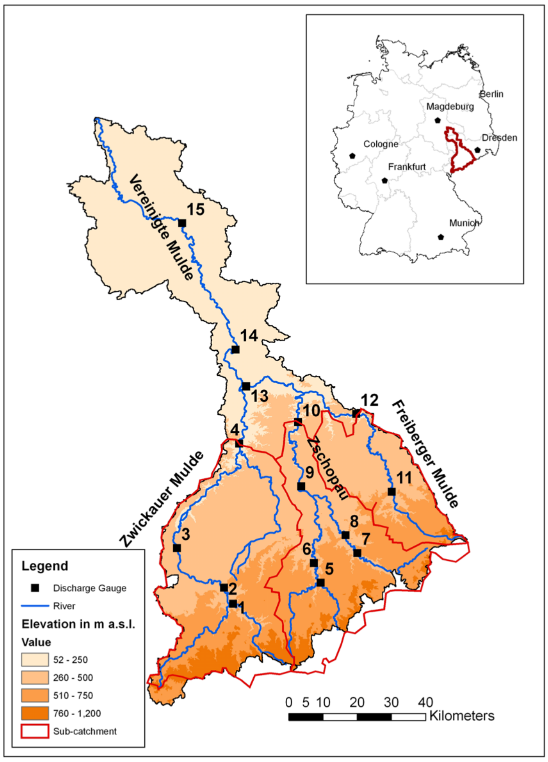


Fig. 1: Study area Mulde catchment: left: discharge gauge locations (numbered according to Table 1) and the digital elevation model; right: geographical location in Germany.

Tab. 1: Analysed discharge gauges in the study area (* stations with one year of missing values).

Number	Gauge	Basin area [km²]	Elevation [m.a.s.l.]	Period of Measure-ments	Mean max. annual flood discharge [m³/s]	Highest value of observation period [m³/s]
1	Aue 1	362	349	1928-2002	66	315
2	Niederschlema*	759	314	1928-2002	111	585
3	Zwickau-Poelbitz*	1030	255	1928-2002	128	683
4	Wechselburg 1	2107	160	1910-2002	213	1000
5	Streckewalde	206	410	1921-2002	30	145
6	Hopfgarten*	529	357	1911-2002	81	420
7	Pockau 1	385	397	1921-2002	69	449
8	Borstendorf	644	356	1929-2002	91	540
9	Lichtenwalde	1575	253	1910-2002	218	1250
10	Kriebstein UP	1757	183	1933-2002	231	1350
11	Berthelsdorf	244	377	1936-2002	35	360
12	Nossen 1	585	204	1926-2002	69	690
13	Erlln	2983	133	1961-2002	329	1550
14	Golzern 1*	5442	118	1911-2002	517	2600
15	Bad Dueben 1	6171	82	1961-2002	474	1760

The region has a long history of large flood events. First written documents about floods, the corresponding water levels and damage can be found from the 9th century onward and more detailed documents starting from the 14th century (Pohl, 2004). It is noteworthy that large winter floods with ice blockage as well as summer floods from torrential storms or long lasting frontal rains caused high damages on infrastructure and agriculture, often with fatalities.

During the last 100 years, three extreme flood events occurred in the study area, namely in July 1954, July 1958 and August 2002. These events will be analysed in more detail in this paper. All of them were caused by large torrential storms. The floods in 1954 and 2002 were triggered by Vb-weather systems. Both flood events in the fifties caused high damage in different parts of the catchment, whereas in 2002 the entire catchment was affected. This flood caused a damage of € 11.6 billion in Germany alone (DKKV, 2004; Thieken et al., 2006b). As a consequence of the flood history, flood defence measures play an important role and have been extended until the present day (DKKV, 2004). Numerous flood retention basins and dams were constructed, which are mainly located in the upper part of the catchment, and significantly influence the discharge downstream.

2.2 Data

Discharge data Over 60 discharge and water level gauges exist in the Mulde catchment. The earliest measurements at regular intervals began in 1910 at two gauges. In order to evaluate the influence of a dam before including data from the downstream discharge gauge into the dataset, daily differences of inflow versus outflow of five large dams for the period 1991 – 2002 were compared. More information from the dam authorities was not available. Inflow and outflow flood peaks were compared and the downstream stations were excluded from the dataset if the flood peak differences were greater than 10%, and if there were at least five affected flood events during this 10 year period. Additionally, daily time series of discharge gauges that are in the immediate vicinity of a dam were compared to daily discharge data from neighbouring gauges at other tributaries. Time series of discharge gauges that did not reflect the hydrograph at the compared gauge station were excluded from the dataset. AMS (hydrological year from November to October) were extracted from daily maximum discharges.

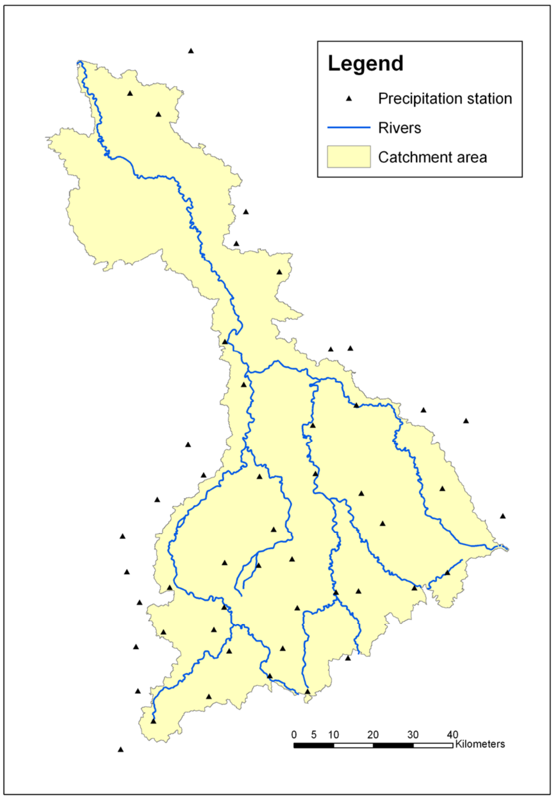


Fig. 2: Locations of the 49 precipitation stations in and around the study area.

A subset of discharge gauges was selected for this analysis which met the following criteria:

- the time series must have a length of at least 40 years,
- the sub-catchment area is larger than 100 km²,
- the flood AMS exhibits no trend,
- the discharge gauges are distributed across the catchment and have a distance of at least 3 km between each other.

15 discharge gauges meet these criteria; they are listed in Fig. 1 and Table 1. For better readability, the gauge stations are listed in all tables in the same order beginning with those located in the south-west (Zwickauer Mulde), then progressing north and east (Zschopau, Freiberg Mulde) and ending with gauges located in the Vereinigte Mulde (cf. Fig. 1).

Precipitation Data Precipitation data were available from the German Weather Service (DWD) at 49 stations in and around the Mulde catchment (see Fig. 2). The data cover the time period between 1952 and 2002 on a daily basis. Daily areal precipitation was calculated based on cubic interpolation for each of the 15 sub-catchments (corresponding to the discharge stations) for the comparison of precipitation and discharge.

Tab. 2: Classification of the form of circulation and its specific pattern (* indicates circulation patterns which are relevant for AMS discharges in the Mulde catchment).

	Circulation pattern		
Form of Circulation	No.	Name	Abbr.
Zonal Circulation	1	West wind, anti-cyclone	WA*
	2	West wind, cyclone	WZ*
	3	Southern west wind	WS*
	4	Angular west wind	WW*
Mixed circulation	5	South-west wind, anti-cyclone	SWA*
	6	South-west wind, cyclone	SWZ*
	7	North-west wind, anti-cyclone	NWA*
	8	North-west wind, cyclone	NWZ*
	9	High pressure system, middle Europe	HM*
	10	High pressure circuit over middle Europe	BM*
	11	Low pressure system, middle Europe	TM*
Meridional circulation	12	North wind, anti-cyclone	NA
	13	North wind, cyclone	NZ
	14	High pressure Iceland, anti-cyclone	HNA
	15	High pressure Iceland, cyclone	HNZ*
	16	High pressure, British Isles	HB*
	17	Trough Middle Europe	TRM*
	18	North-east wind, anti-cyclone	NEA
	19	North-east wind, cyclone	NEZ*
	20	High pressure Fennoscandia, anti-cyclone	HFA*
	21	High pressure Fennoscandia, cyclone	HFZ
	22	High pressure Norwegian Sea-Fennoscandia, anti-cyclone	HNFA
	23	High pressure Norwegian Sea-Fennoscandia, cyclone	HNFZ
	24	South-east wind, anti-cyclone	SEA
	25	South-east wind, cyclone	SEZ*
	26	South wind, anti-cyclone	SA
	27	South wind, cyclone	SZ
	28	Low Pressure, British Isles	TB*
	29	Trough, Western Europe	TRW*
	30	Transition, no classification	U

Atmospheric circulation patterns Information about the predominant European circulation pattern for each day was available from the "Catalogue of Großwetterlagen in Europe 1881 – 2004" (Gerstengarbe and Werner, 2005). The catalogue distinguishes three large circulations, which are divided into 30 different circulation patterns (one is classified to be a "transition class") (Table 2). The Vb-weather system is represented by the patterns TM (low Middle Europe) and TRM (Trough Middle Europe).

The circulation patterns comprise the zonal circulation form, the mixed circulation form as well as the meridional circulation form. For every day a circulation pattern is assigned to be the dominant one for Europe. Through the specific distribution of lows and highs over Europe, it may therefore be possible that the dominant circulation pattern of a particular day is not necessarily representative for the Mulde catchment. This is for instance the case, if the Mulde catchment is still under the influence of a weakened low, which is however already situated above Eastern Europe, whereas the dominating European circulation pattern is above Western Europe. However, other than this catalogue, more detailed meteorological data for the study area were not available.

3 METHODOLOGY

3.1 Flood frequency analysis

The distribution-free and non-parametric Mann-Kendall test for Trend (one-sided test; significance level: α = 0.05) was used for the detection of trends in the data. Since small trends in the data may not be detectable, for instance by the Mann-Kendall test (Bárdossy and Pakosch, 2005), a regional test of stationarity was conducted with all 15 data sets (Lindström and Bergström, 2004). To this end, several data series from the same region, that cover the same period of measurements, are tested jointly (also with the Mann-Kendall test). For comparison, the discharge data were divided by the MAF (mean maximum annual flood discharge) of the respective series. AMS of 13 gauge stations with data from 1936 to 2002 and of two gauges with data from 1961 to 2002 were included.

Independence of the data was ensured by using AMS data, which were also checked for possible dependent values around the turn of a hydrological year. For this, a threshold time of 7 days between two AMS floods was included, which guarantees the independence of two close-by flood events, since the time of concentration for this basin is smaller than 7 days.

Flood frequency analyses were performed with seven different distribution functions (Gumbel, Weibull, 2-parametric LogNormal, Generalised Extreme Value (GEV), General Logistics (GL), 3-parametric LogNormal, and Pearson type III) with both the Method of Moments and with the L-Moments (Hosking and Wallis, 1997; Institute of Hydrology, 1999). The GEV and GL distribution functions (both with L-Moments) revealed the best fits based on the Kolmogorov-Smirnov-Test and visual examination relative to the empirical probabilities (Test hypothesis: F(x) = CDF for all x with α = 0.05). Emerging consensus can be found in many studies worldwide that the GEV distribution reveals the best fits (Pearson, 1991; Onoz and Bayazit, 1995; Vogel and Wilson, 1996; Douglas and Vogel, 2006). The Institute of Hydrology (1999) also describes the "theoretical and historical importance" of the GEV. Hence, subsequent analyses were performed using the GEV.

3.2 Spatial distribution of flood characteristics

The spatial distributions of the statistical moments of the AMS, such as skewness and coefficient of variation, were analysed to detect possible differences among sub-catchments. The spatial extent and distribution of the three most extreme flood events (July 1954, July 1958, August 2002) were analysed in more detail. For every event and gauge station, return periods (GEV, L-Moments) were calculated. These estimates were then assigned to each river segment upstream of the 15 gauge stations in order to analyse the flood characteristics in a spatially explicit manner.

Moreover, the AMS of 11 gauge stations with data from 1929 to 2002 (74 years) were studied with respect to the spatial distribution and magnitude of flood events. To this end, the number of different flood events per year in the catchment was analysed. If all 11 gauges have their highest discharge of a certain year on the same day (+/- 1 day), the number of flood events for that year will be one. The other extreme is that all gauges have their highest peak at another time of the year. In that case, the number of flood events for that year is 11.

3.3 Relationship between precipitation maxima and discharge maxima

The relationship between precipitation maxima and discharge maxima was studied in more detail. Areal precipitation was calculated for the three large sub-catchments (Zwickauer Mulde: gauge Wechselburg; Zschopau: gauge Lichtenwalde; Freiberger Mulde: gauge Nossen) and the Vereinigte Mulde at the gauge Golzern. Precipitation sums of 24 h, 48 h and 72 h of the flood events were compared to discharge maxima. The four discharge stations are distributed over the entire catchment and represent the large sub-catchments. Rainfall AMS were extracted from the precipitation data and then compared on a seasonal basis to the discharge AMS to determine, how many large precipitation events are reflected in the discharge AMS.

3.4 Circulation pattern and flood generation

Daily data of circulation patterns between 1911 and 2002 were analysed in order to obtain an overview about the seasonal distribution and frequency of the circulation patterns in Europe. Additionally, the circulation patterns, which are triggering the AMS discharges, were assigned to the AMS flood data of the gauge Golzern. The gauge at Golzern is representative for the entire catchment, because it comprises 88% of the catchment area. As the first gauge at the Vereinigte Mulde it represents the influence of the two large sub-catchments. Moreover it has a long time series (1911 – 2002) compared to nearby gauges such as Bad Düben or Erlln (both 43 years).

From the AMS data, empirical probabilities were assigned to the flood events and then combined with the circulation pattern data. With this information, it is possible to estimate the potential of a circulation pattern to generate a flood of a certain return period.

4 RESULTS

4.1 Testing for trends in the flood AMS

The one-sided Mann-Kendall test for increasing trend (significance level $\alpha = 0.05$) revealed no trends for all 15 gauge stations. The trend test for regional stationarity was performed with the normalised AMS of the 15 gauge stations. As Fig. 3 shows, the data exhibit a very small positive trend in the regional trend analysis. When the flood event from August 2002 was excluded from the data, the slightly positive trend became slightly negative. The Mann-Kendall test showed no trend (significance level $\alpha = 0.05$). Therefore the data were used for flood frequency analysis.

4.2 Seasonal occurrence and magnitude of floods

Two dominant flood process types in the Mulde catchment can be extracted from the data. During March and April, a first peak in the discharge AMS occurs during snow melt and "rain on snow" flood events. The second peak occurs in July and August, when large torrential storms traverse the area (Table 3). At all 15 discharge stations winter floods (November – April) comprise a larger part of the AMS than summer floods. In the upper western part of the Erzgebirge (corresponding to the gauges at Aue, Niederschlema, Zwickau), the percentage of summer and winter floods in the AMS is almost equal (e.g. Aue: 46% summer floods; 54% winter floods), whereas in the eastern part of the catchment winter floods have larger percentage (59% – 69%).

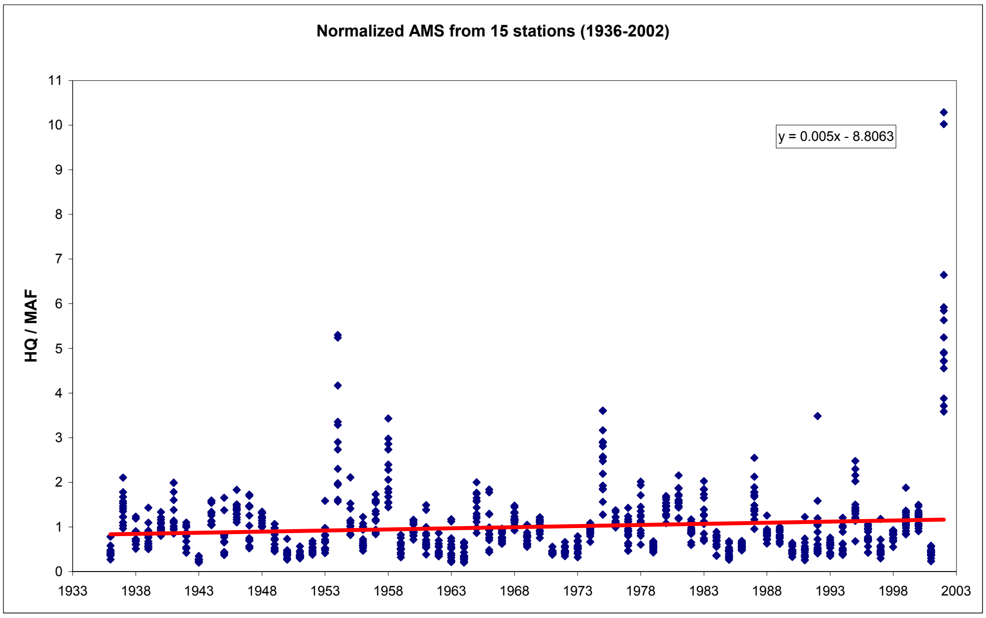


Fig. 3: Regional trend test based on discharge data of 15 stations.

Tab. 3: Monthly relative frequency of discharge AMS (in percent).

Gauge	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Aue	8	4	9	24	8	5	15	8	7	4	3	5
Niederschlema	5	5	12	23	8	8	15	7	4	4	1	7
Zwickau	4	5	11	20	8	9	16	7	4	4	3	8
Wechselburg	12	8	13	9	5	8	17	9	1	2	5	12
Streckewalde	11	9	16	17	5	7	17	9	0	4	1	5
Hopfgarten	13	10	14	11	7	8	12	7	1	5	1	11
Pockau	11	11	17	10	10	6	12	7	2	4	2	7
Borstendorf	8	9	20	14	9	5	11	7	1	4	3	8
Lichtenwalde	13	14	19	10	6	5	9	9	1	2	1	11
Kriebstein	9	11	19	14	7	7	10	7	1	3	1	10
Berthelsdorf	7	13	24	7	9	3	10	7	1	1	1	13
Nossen	10	16	23	5	6	4	9	6	3	3	3	12
Erlln	10	12	26	10	7	2	7	12	2	2	0	10
Golzern	14	12	16	9	5	7	11	9	2	3	3	8
Bad Düben	10	10	26	12	7	2	10	10	2	2	0	10

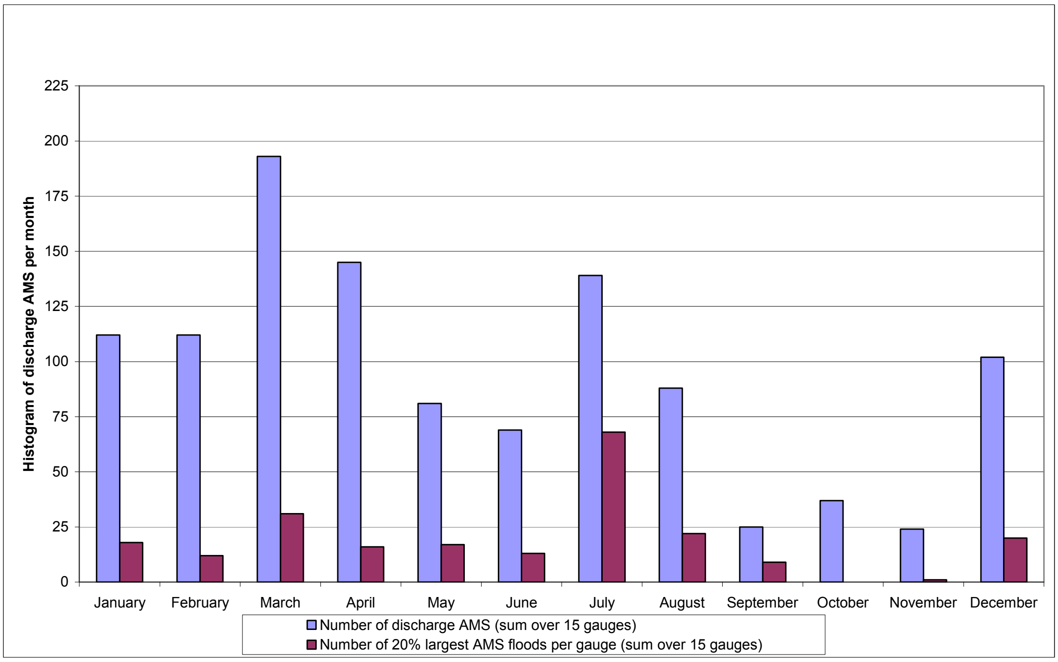
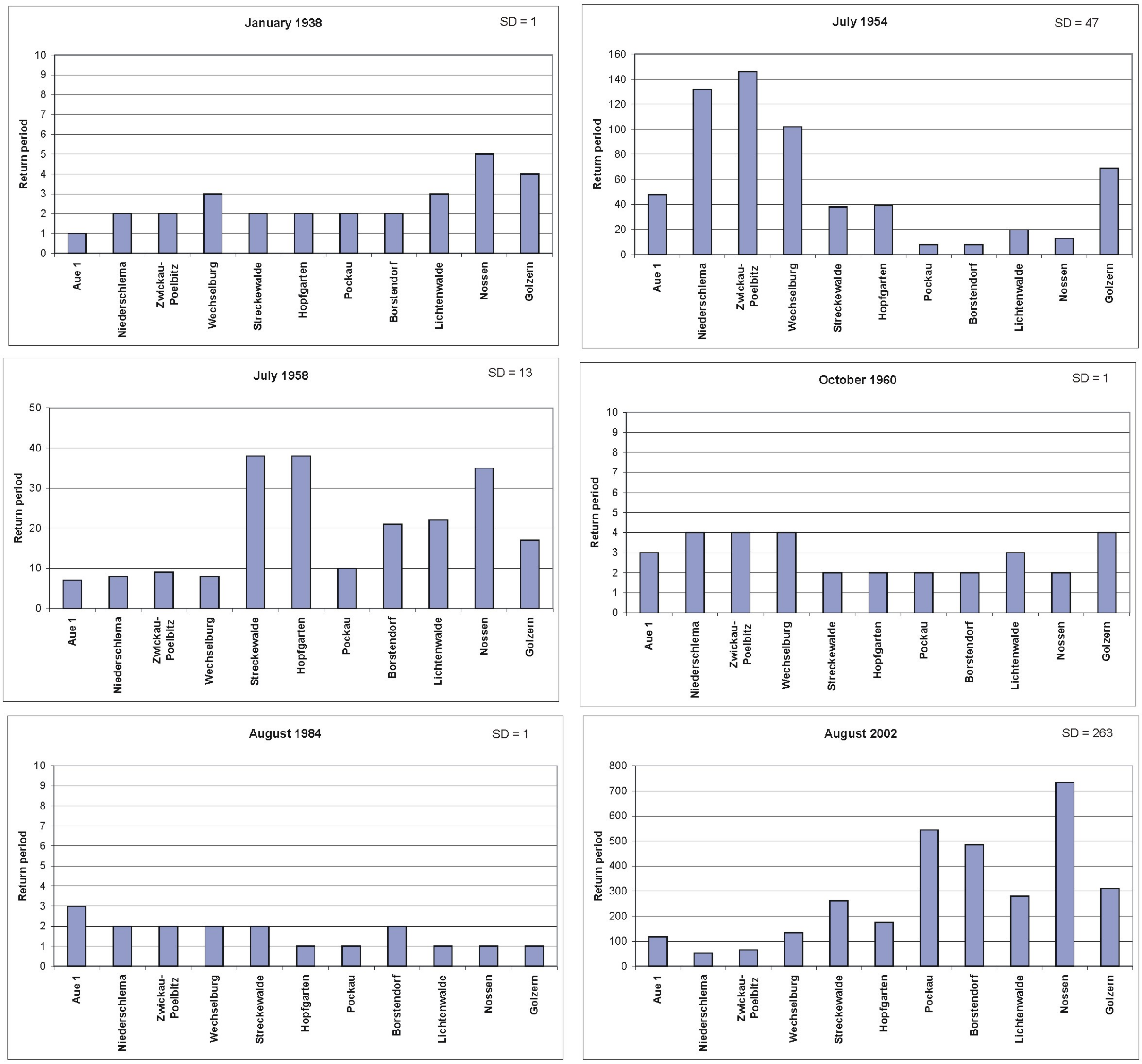


Fig. 4: Monthly distribution of the number of discharge AMS, summed up over the 15 gauges for all AMS floods and for the 20% largest events.

The winter floods are usually small events with a low return period. They constitute at all 15 gauges only 8 – 21% of the 20% of the largest floods. Summer flood events, on the other hand, are less frequent, but cover a larger proportion of extreme events (26 – 39%). In Fig. 4 the data of Table 3 are summed up for all 15 gauges. Additionally, the monthly distribution of the 20% largest flood events is shown. Again, it is visible that winter floods have a large percentage of the AMS, but the most extreme events occur during the summer. From these analyses we could conclude that summer flood events play a more important role for the flood hazard estimation of extreme events, which would necessitate the usage of Summer Maximum Series (SMS) instead of AMS. A comparison of return periods estimated with AMS and SMS for the three extreme flood events showed however that estimated return periods up to 270 years are at all 15 gauges much lower with AMS. As an example return periods (GEV) for the gauge Aue are shown for the three floods 1954: 48 (AMS), 65 (SMS); 1958: 7 (AMS), 10 (SMS); 2002: 115 (AMS), 143 (SMS). Thus, a larger discharge would be needed to estimate the same return period, e.g. a design discharge of 100 years when using AMS compared to SMS. Estimates for return periods larger than 270 years show, however lower values with SMS. Therefore, flood protection measures designed on the basis of AMS estimated return periods provide safety margins, even for extreme summer events up to 250 years.

4.3 Spatial distribution of flood characteristics

The AMS of 11 gauge stations with data from 1929 to 2002 (74 years) were studied with respect to the spatial distribution and magnitude of flood events. To this end, the number of different flood events per year in the catchment was analysed. In 13 years of the 74-year period, one flood event occurred that affected all 11 sub-basins, whereas in 18 years no dominant flood event (i.e. four to seven flood events per year) could be identified. These are summer and winter events. In most years (27) three different flood events are related to AMS discharges.



January 1938 SD = 1

July 1954 SD = 47

July 1958 SD = 13

October 1960 SD = 1

August 1984 SD = 1

August 2002 SD = 263

Fig. 5: Variation of return periods for six different floods (SD = standard deviation).

In Fig. 5 six different flood events at the 11 analysed gauges and their respective return periods are shown. The return periods were estimated with the GEV (L-Moments). The six flood events comprise the three largest events in the catchment (1954, 1958, 2002) and three small catchment-wide events. Events with discharges that correspond up to a 10-year peak discharge are mostly homogenously distributed across the catchment. They have similar return periods at all gauges and exhibit a standard deviation of 1. This is shown for the floods in January 1938, October 1960 and August 1984. Events with discharges larger than a 10-year peak exhibit increasing spatial distinctions as well as increasing standard deviations. This is illustrated by the floods in 1954, 1958 and 2002. Depending on the location of the precipitation field, one or the other sub-catchment is more affected during a large flood event.

Figure 6 shows the spatial distribution of the return periods that were calculated for the observed discharges of the three most extreme flood events (1954, 1958, 2002) in the Mulde catchment (upper part) and the corresponding areal precipitation events (lower part). The return period calculated for a certain gauge was assigned to the river segment upstream of the gauge. A marked spatial distribution can be seen. For the flood event in 1954, high return periods were calculated for the western part of the catchment. This is explained by the rainfall event that had its centre in the western part. The floods in 1958 and 2002 were caused by precipitation events with their centres east of, or in the eastern part of the study area. Figure 6 illustrates the direct relationship between the location of the precipitation field and the flood return period for the three events.

More similar statistical moments were found along the tributary rivers rather than according to the elevation of the gauge locations. In the beginning the assumption was made that the gauges in the mountains of the Erzgebirge can be grouped together to exhibit similar statistical moments as well as the gauges in the lowlands. However, increasing values of the statistical moments occur from west to east that corresponds to the division of the sub-catchments. Figure 7 shows the spatial distribution of the skewness (A) and the coefficient of variation (B) for the 15 gauges. The sub-catchment of the Zwickauer Mulde and the western part of the Zschopau (gauges 1 – 6 in Table 1) are more homogeneous and differ significantly (CI 95%) in its statistical moments from the eastern part of the catchment. These results suggest a different distribution of the precipitation in the sub-catchments which in turn leads to differences in the discharge behaviour. Another possibility is that the landscape characteristics are largely responsible for these differences, which is discussed in the following section.

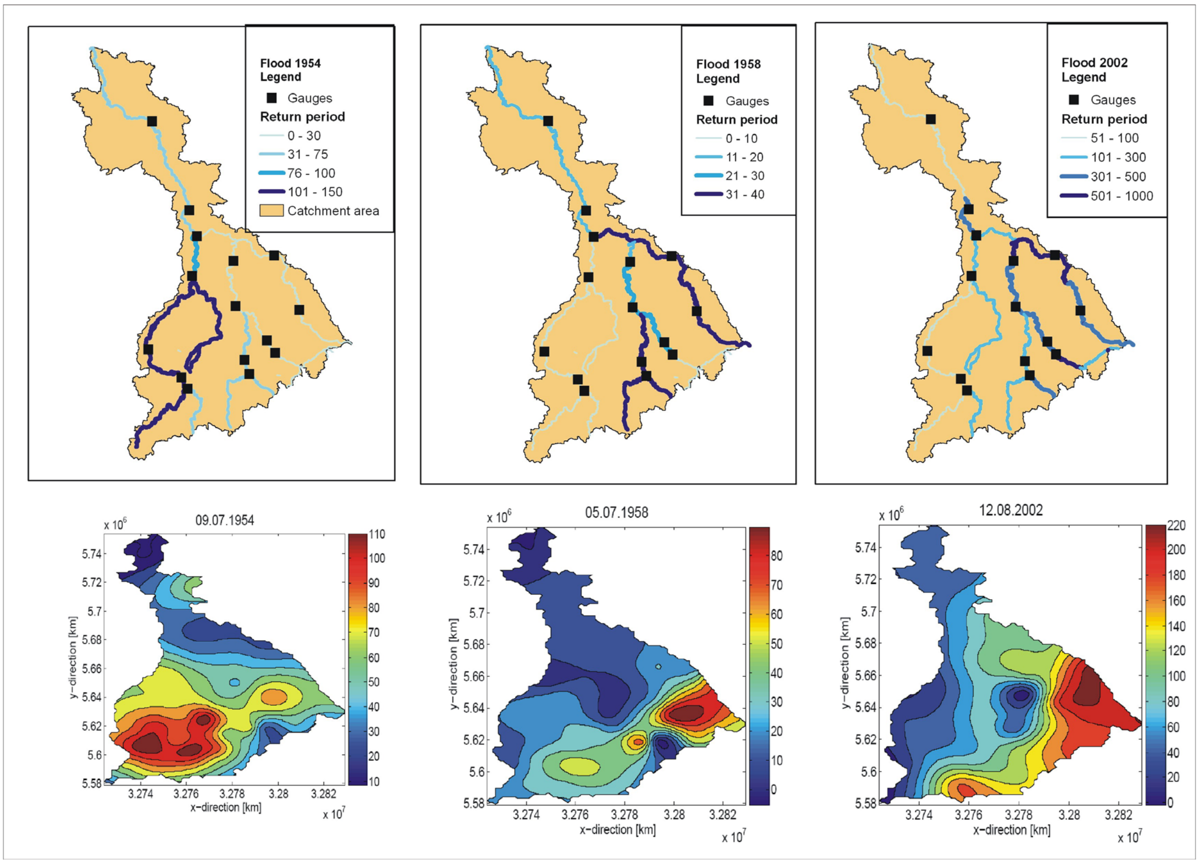


Fig. 6: Estimated return periods (GEV, L-Moments) for the floods in 1954, 1958, 2002 (period 1929 – 2002 (above)) and the corresponding precipitation fields (below). Note that for a better illustration of the spatial distribution the classes of discharge return periods and precipitation amounts differ.

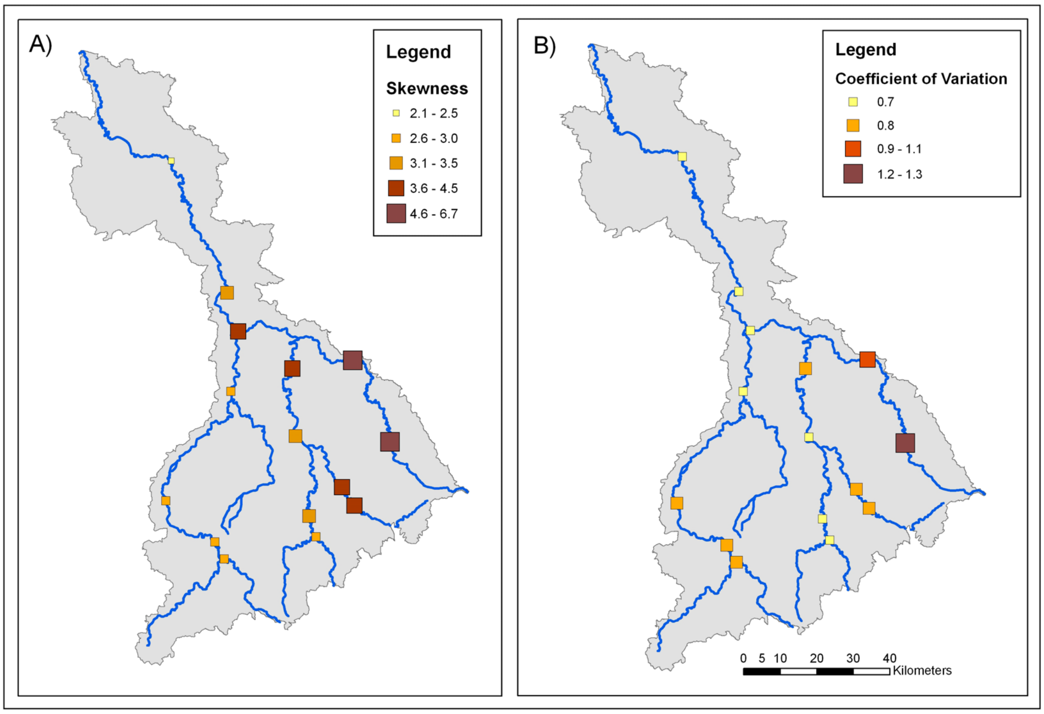


Fig. 7: Skewness (A) and coefficient of variation (B) of the discharge AMS for the 15 gauges.

Tab. 4: Percentages of the dominating landscape characteristics.

		Zwickauer Mulde	Zschopau	Freiberger Mulde
Land use	Urban areas	12 %	7 %	7 %
	Agricultural land	52 %	60 %	70 %
	Forest	32 %	33 %	18 %
Soil	Cambisols and Planosols	88 %	94 %	90 %
Hydrogeology	No or small local groundwater reservoirs	94 %	99 %	99 %
Geology	Metamorphic or plutonic rocks	66 %	91 %	85 %

4.4 Landscape characteristics

The land use is dominated forest covered mountains and intensively used agricultural lowland. The proportion of agriculturally-used areas increases from west to east and south to north, whereas the percentage of forest decreases. Urban areas only play a role in the sub-catchment Zwickauer Mulde with two larger cities (Zwickau, Chemnitz). Meadows and pastures are homogenously distributed across the area with a slightly larger area in the upper middle Erzgebirge.

Table 4 shows the main percentages of the analysed landscape characteristics. It can be seen that no major differences in soil (type of soil with information on soil depth, texture, conductivity, etc.), bedrock, groundwater flow and land use can be distinguished among the three large sub-catchments.

As we can see landscape characteristics, such as soil and hydrogeology, do not vary much between the sub-catchments. Although there are slight differences in the land use, there is much evidence in the literature that during extreme events the land use only plays a minor role (e.g. DKKV, 2003). Thus, the dominant influence seems to be exerted by precipitation and weather characteristics, which is discussed in the following two sections.

4.5 Relationship between precipitation AMS and discharge AMS

AMS of precipitation and discharge were therefore compared to determine how well precipitation and discharge AMS coincide. Different precipitation AMS were extracted from sums of one, two and three days. A time lag of two days between the precipitation event and the discharge peak was allowed. Table 5 shows exemplarily for four discharge stations the percentages of agreement for summer and winter separately.

During the winter, the precipitation events are not so clearly and directly reflected in the discharge data (agreement 7 – 26 %). One reason for this can be found in the topography of the catchment. During the winter time, large amounts of the precipitation can fall as snow in the Erzgebirge and the water is stored in the snowpack. The discharge generation is delayed until melting starts. Therefore, the triggering circulation pattern, which may have brought a major snow cover, cannot be directly related to the corresponding discharge peak. On the contrary, a direct connection between a large summer rain event and a large discharge can be found in the summer throughout the catchment (agreement 59 – 89%). Based on these findings the question was posed if large summer flood events can also be related to a specific circulation pattern. This question will be answered in the following section.

Tab. 5: Percentages of agreement between precipitation AMS (precipitation sums of 24 h, 48 h and 72 h) and discharge AMS.

	24 h		48 h		72 h	
Gauge	Summer	Winter	Summer	Winter	Summer	Winter
Wechselburg	65 %	7 %	61 %	7 %	70 %	10 %
Lichtenwalde	88 %	20 %	88 %	7 %	71 %	14 %
Nossen	78 %	15 %	89 %	26 %	83 %	26 %
Golzern	59 %	20 %	68 %	17 %	68 %	20 %

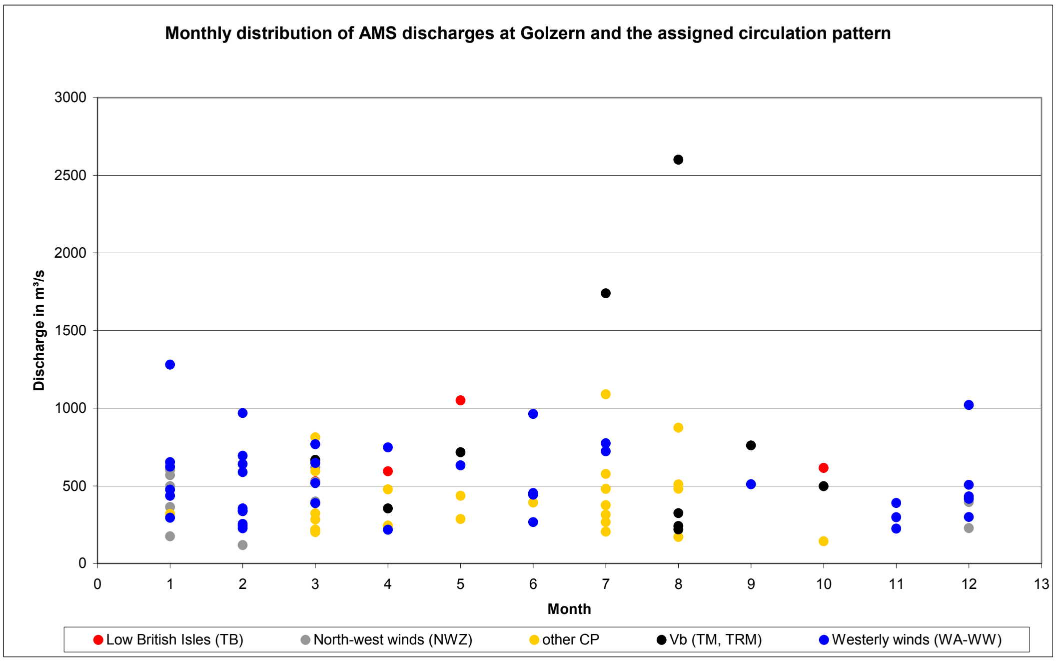


Fig. 8: Monthly distribution of AMS discharges at Golzern and the assigned circulation pattern.

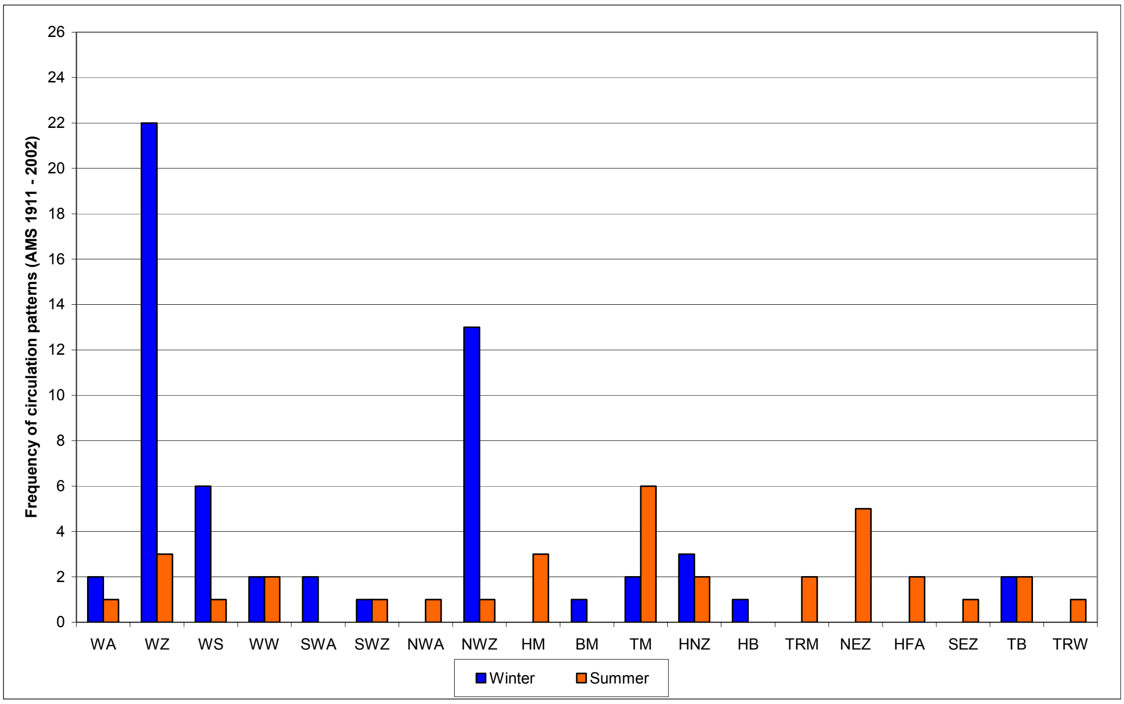


Fig. 9: Histogram of the circulation patterns at the gauge Golzern that generated AMS discharges between 1911 and 2002 (abbr. see Table 2).

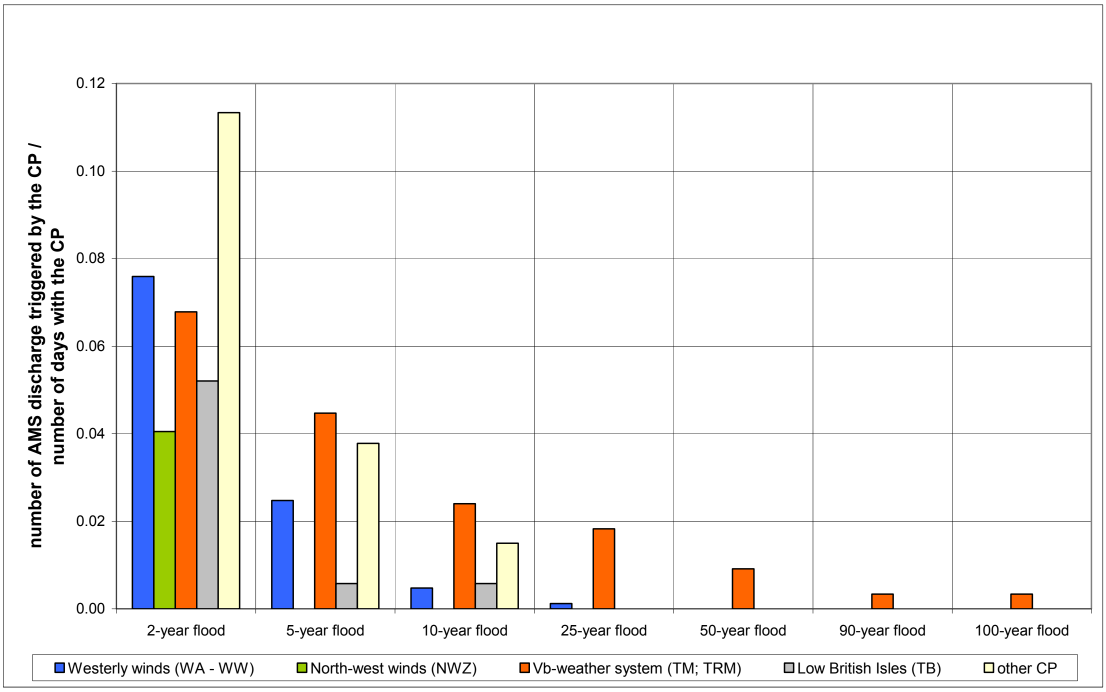


Fig. 10: Flood potential of different circulation patterns to cause a flood of a certain return period.

4.6 Circulation pattern and flood generation

First of all, daily information about the dominating European circulation pattern between 1911 and 2002 were analysed. For the entire period, westerly winds (WA – WW) cover about 25% of the total circulation patterns; high pressure weather regimes (all circulation patterns beginning with the letter "H") cover about 27%. The proportion of the Vb-weather regime (TM and TRM) is relatively low with 6.5%.

The analysis of the discharge AMS at the gauge Golzern shows that approx. 60% occur during the winter time and 40% during the summer time. Only 19 out of the 30 circulation patterns (cf. Table 2) play a role in creating AMS discharges in the Mulde catchment. Thus, 11 out of 30 CPs have not created an AMS discharge within the 92 years. In the winter (November – April), the cyclonal western and north-western patterns (WA – WW; NWZ) play the dominant role in flood generation, because they account for 84% of the AMS winter discharges and 100% for the floods from November until February (see Fig. 8). The summer AMS discharges are generated by several different CPs, though mainly by westerly cyclones (WA-WW), north-east cyclones (NEZ) and the troughs over central Europe (TM, TRM). Figure 9 illustrates the distribution separately for summer and winter.

To answer the question, which circulation pattern is likely to generate large floods in the Mulde catchment, the flood potential was calculated as the probability for a flood quantile HQ_T, given a certain CP:

$$P(HQ_T \mid CP_X) = \frac{n_{HQ_T}}{n_{CP_X}} \tag{1}$$

where n_{HQ_T} is the number of flood events larger than HQ_T (e.g. the 10-year flood) that have been triggered by a certain circulation pattern CP_X, whereas n_{CP_X} is the number of days with the corresponding circulation pattern. It is important to note that already for small return periods (5 years) the Vb-weather regime (TM, TRM) has the highest flood potential (Fig. 10). These circulation patterns occur seldom, however they are associated with high discharge peaks. Their flood potential is even more pronounced for floods of larger return periods. Weather patterns, such as the westerly and north-western cyclones, which are responsible for most of the winter AMS discharges, play only an important role for return periods of max. 10 years.

There exist also Vb-weather regimes that generated floods with low return periods at the gauge Golzern. However, they often caused high damage in other catchments in Europe and had their precipitation centre outside the Mulde catchment. This is for example the case for the flood in April 1930 in Bavaria, the August 1984 flood in Switzerland, and the flood in July 1997 in the Odra catchment, when the Czech Republic and Poland were heavily affected (Grünewald et al., 1998; Wasserwirtschaftsamt Bayreuth, 2006).

Analyses of the other gauge stations as well as historical records of large floods in the Mulde catchment show similar results with the highest floods being generated by Vb-weather regimes. From this analysis we can conclude that although Vb-weather pattern do not occur often in the European weather regime they carry a large flood risk in the Mulde catchment.

5 CONCLUSIONS

Analyses of discharge series, precipitation fields and flood producing atmospheric circulation patterns revealed two governing flood regimes in the Mulde catchment in south-eastern Germany: (1) frequent floods during the winter with generally low return periods and (2) less frequent floods during the summer, which can reach remarkable flood peaks.

Differences in the statistical parameters of the discharge data are found in the catchment from west to east, which are however not reflected in the landscape characteristics such as soil, elevation or land use. It is suspected that the location and the duration of the precipitation field are the most influencing factors for the discharge.

The usage of SMS could seem appropriate for extreme events in this catchment. However, return periods based on SMS revealed underestimations of extreme discharges up to a return period of 270 years. Estimates for even larger events showed underestimations with the AMS. Thus, flood protection measures for design floods up to 250 years based on estimations from AMS are still recommended. From these analyses we can conclude that for catchments with two or more flood regimes it is not always necessary to separate these from the AMS given that the extreme events are well represented by the AMS and thus flood protection measures are designed with safety margins. However, a thorough analysis of the flood characteristics of a catchment as well as flood producing weather regimes is of great importance for reliable flood estimates. In view of the climate change it is necessary to gain information about weather regimes that trigger large flood events in the region of interest and possible trends of these. With the combined information of catchment characteristics, flood behaviour and weather patterns, the uncertainty in the estimation of extreme events can be reduced.

Acknowledgements

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References can be found at the end of the thesis.

Paper 3: Scenario-based modelling studies to assess the impact of climate change on floods in the German Rhine catchment

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Abstract

The aim of the study is to analyse the impact of global climate change on regional hydrology with special emphasis on discharge conditions and floods. The investigations are focussed on important sub-catchments in the German Rhine catchment where a chain of models was applied: Large scale atmospheric fields, simulated by two different Global Circulation Models (GCMs) that were driven by the emission scenario IS95a ('business as usual') were used as input to the method of expanded downscaling (EDS). EDS delivers local time series of scenario climate variables (precipitation, temperature) as input to HBV-D, a hydrological model that simulates runoff under present as well as scenario climate conditions. Observed and simulated time series of discharge were analysed in order to assess possible future runoff conditions under the impact of climate change. The study indicates a potential increase in mean runoff and flood discharge for small return intervals. However, the uncertainty range that originates from the application of the whole model chain and two different GCMs is high. This leads to high cumulative uncertainties, which do not allow conclusions to be drawn on the development of future extreme floods.

Keywords: Climate change, Regional hydrology, Floods, Uncertainty

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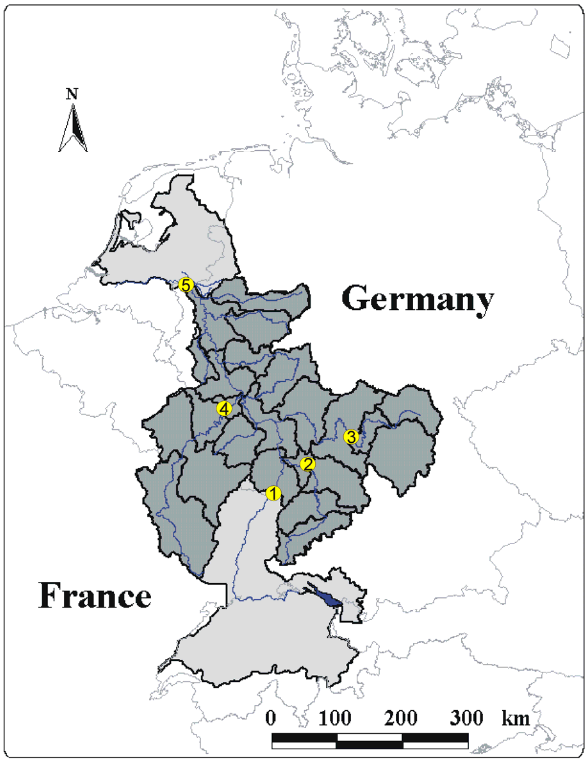
1 INTRODUCTION

The issue of climate change and the future development of runoff and flood conditions is of high priority within water resources research and a number of studies have dealt with regional impact analysis and their uncertainties (Bergström et al., 2001; Menzel and Bürger, 2002; Prudhomme et al., 2003). So far, only a few investigations on the possible impact of climate change have been carried out for the river Rhine, although it is the most intensively used inland waterway in the world. At Lobith/Emmerich, on the German-Dutch border, around 170,000 ships pass per year. The catchment of the river Rhine represents an international catchment with water resources and flood problems shared by nine European countries (Fig. 1). Its total area amounts to 185,000 km² whereof 100,000 km² is located in Germany.

Observations indicate an over-proportional increase of surface temperatures in Central Europe over the last 100 years in comparison to the global mean value of + 0.6 ± 0.2 K (IPCC, 2001; Müller-Westermeier and Kreis, 2002). Investigations on changes in large-scale precipitation characteristics prove that the development of annual precipitation totals in Germany shows a distinct behaviour, with an increasing trend in the western part and a clear reduction over large areas in Eastern and South-eastern Germany. This is a direct consequence of changes in the frequency and mean residence time of certain weather conditions. For example, the occurrence of relatively warm westerly patterns during winter, causing extended rainfall and snow melt and thus triggering the formation of floods, has significantly increased over extended parts of Western and Central Europe, especially within the last 30 years (Werner et al., 2000). Moreover, the increase of precipitation totals in winter has often been accompanied by increased precipitation intensities in these areas (Osborn et al., 2000; LfU, 1997). The drainage basin of the German Rhine catchment, extending over South-western and Western Germany (Fig. 1), is located within the reach of these circulation patterns and has thus been affected by the changes described. Consequently, the analysis of measured discharge time series indicated a rise in flood incidents within the last 30 years, both for the Rhine itself (Bendix, 1997) and several of its tributaries (KLIWA, 2000; Caspary, 1995). However, if the analysis is extended over a longer time period, only weak trends towards increased discharge or even reductions in peak flow conditions can be detected (KLIWA, 2000).

The objective of the present study is to apply climate change scenarios to simulate the long-term behaviour of runoff conditions in the German part of the Rhine catchment between the Maxau and Emmerich gauges on the river Rhine and to investigate possible future changes, especially changes in the frequency and magnitude of floods as well as their uncertainties. The results shown in this paper focus on investigations at gauges located on the most important tributaries of the river Rhine (Fig. 1, Table 1).



Tab. 1: Overview of important discharge gauges in the area under investigation as shown in Fig.1.

No	Discharge gauge	River	Catchment area [km²]
1	Maxau	Rhine	50196
2	Rockenau	Neckar	12710
3	Würzburg	Main	14017
4	Cochem	Mosel	27088
5	Emmerich	Rhine	159555

Fig. 1: The catchment of the Rhine (shaded area). The dark grey surface marks the area under investigation, covering the drainage basin between the Maxau and Emmerich gauges. The figure also illustrates the subdivision of the area under investigation into 23 sub-basins as well as the main river paths. The numbers refer to the discharge gauges listed in Table 1.

2 PROCEDURE AND METHODS

In order to investigate impacts of climate change on regional hydrology, a chain of models is needed (Fig. 2): Global Circulation Models (GCMs) with emission scenarios as boundary conditions provide global circulation fields until the year 2100. However, data from GCMs cannot be processed directly in regional modelling studies. The spatial resolution of GCMs is far too coarse and does not capture smaller scale climate effects (Cubasch 2001). In order to bridge this scale gap downscaling methods have become popular. They translate global circulation fields into local climate variables such as precipitation and temperature. For this study, the technique of expanded downscaling (EDS) developed by Bürger (1996; 2002) was applied. Local time series of precipitation and temperature serve as an input for hydrologic simulations. Runoff simulations were performed by the HBV-D model (see below).

The linkage of this chain of models (GCMs, EDS and HBV-D) and the related work items are illustrated in Fig. 2. Further details are given in the following sections.

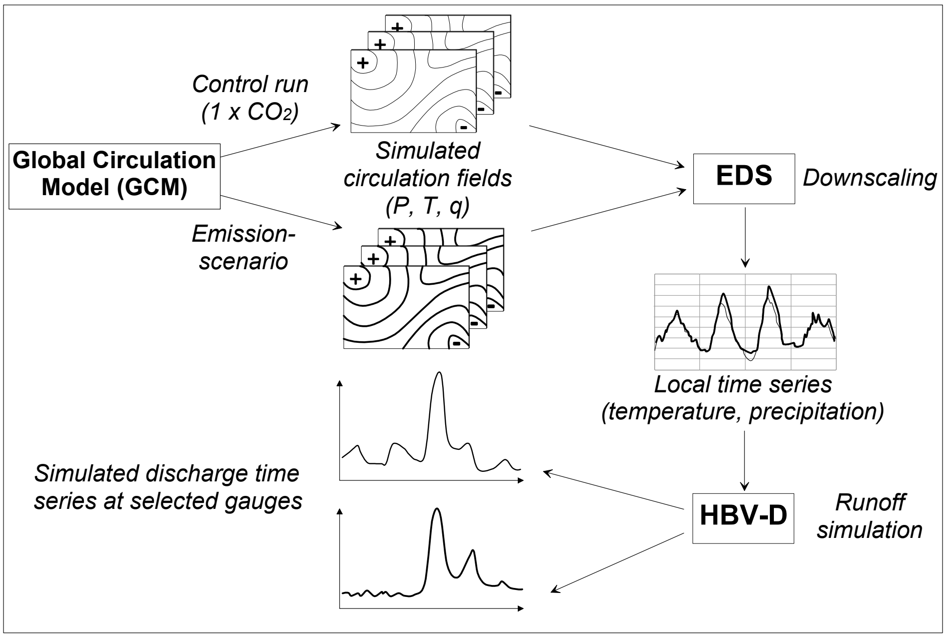


Fig. 2: Overview of the model chain that translates simulated circulation fields into local climate time series for input to hydrological modelling. P, T and q refer to air pressure, air temperature and specific humidity, respectively.

2.1 The hydrological model

A preliminary task for modelling purposes was to subdivide the large-scale investigation area into 23 sub-basins, with areas ranging from approx. 3,000 to 12,000 km² (Fig. 1). This allows a better consideration of regional characteristics, and the performance of the hydrological model is expected to increase (Krysanova et al., 1999). The simulations were carried out using the hydrological model HBV-D (Krysanova et al., 1999) which is a derivative of the 'Nordic' HBV model (Saelthun, 1996), but allows the consideration of up to 15 land cover types. HBV-D can be classified as a conceptual, semi-distributed model, with sub-basins as primary hydrological units.

HBV-D was adjusted to the specific relief, soil and land use characteristics of the individual subbasins. Daily precipitation and temperature data were provided by a total of approximately 600 climate and precipitation stations which are evenly distributed over the whole area investigated. The calibration of HBV-D and the validation of model performance were based on daily discharge data at the outlets of the 23 sub-basins shown in Fig. 1. The reference time interval for model calibration and validation included at least 35 years starting from 1961, with calibration periods extending over 10–15 years. In general, the model reproduces the discharge conditions fairly well in all investigated sub-basins. Both individual flood periods and the long-term runoff behaviour are reflected well by the model.

2.2 Downscaling of measured and simulated atmospheric fields

An expanded regression method, i.e. Expanded downscaling (EDS) described by Bürger (1996; 2002), was used to link the characteristics of large-scale pressure fields to local weather variables. The calibration of the regression parameters of EDS was applied to daily large-scale pressure fields *P* at the 500 hPa geopotential height, 850 hPa temperature *T* and 700 hPa specific humidity *q* observed in the period 1961-1995 and delivered by the National Centre of Environmental Prediction (NCEP; www.ncep.noaa.gov). The simulated daily local weather was then compared with measured meteorological variables. Furthermore, the generated data were passed to the hydrological model HBV-D in order to simulate runoff from the downscaled climate. These simulations were compared with measured discharge and were used for a further adjustment of the calibration parameters of EDS (Menzel and Bürger, 2002).

EDS was then applied to simulated daily atmospheric fields, delivered by two different GCMs. In this study, GCM outputs from the ECHAM4/OPYC3 model (Roeckner *et al.*, 1999) and from the HadCM3 model (Gordon *et al.*, 2000) were used. Both models are driven by emission scenarios determined by the Intergovernmental Panel on Climate Change (IPCC; www.ipcc.ch). The basic forcing in this study is the emission scenario IS95a (IPCC, 1995), commonly termed the 'business as usual' scenario, with a 1 % per year compound rise in radiative forcing. The GCM runs were driven by IS95a for the period 1990–2100. For the preceding time intervals, historic measurements of atmospheric greenhouse gases were used. Data from a simulation run for the period 1860–2100 were available from ECHAM4/OPYC3 while HadCM3 delivered data for the period 1961–2100. In addition, data from a so-called control run with ECHAM4/OPYC3 were used. In this case, the GCM was driven by a constant greenhouse gas concentration, roughly representing the status of the year 1990. With these unmodified boundary conditions the model was run over 300 years. The generated data set is considered to represent the whole range of possible natural variability and therefore serves to mark off effects of a changing climate derived by the scenario runs from assumed natural conditions.

After the generation of local climate data from the GCM output by EDS, the hydrological model HBV-D was applied to simulate discharge over the whole scenario period.

3 RESULTS

When presenting and interpreting results of climate change impact studies it is important to be aware of the fact that the climate scenarios are completely independent from the climate measurements in terms of their temporal attachment. That is, the scenarios can only be compared among themselves or with measurements by means of the long-term statistical behaviour of the individual time series.

The application of the described model chain yield clear temperature increases (between +1.6 and +2.6 °C for the period 2061–2095, depending on both the considered GCM and the related sub-basin) and precipitation rises (between +18 and +45 % for the period 2061–2095) for the over-all German Rhine basin. In general, the downscaled information from the ECHAM4/OPYC3 model delivers more pronounced scenarios (both stronger temperature and precipitation increases) in comparison to HadCM3.

3.1 Climate change scenarios and mean annual discharges

The impact of climate change on hydrological conditions was analysed for mean annual discharges over the periods 1961–1995 and 2061–2095. Fig. 3 exemplarily shows results for the three sub-basins Main, Mosel and Neckar. Compared to the mean annual discharge derived from daily measurements 1961–1995, the performance of the HBV-D model driven by measured climate data (the black bars in Fig. 3) has proved to be good in all investigated catchments as deviations in relation to measurements do not exceed ± 10 %.

Discharge simulations based on downscaled climate information for the reference period 1961–1995 overestimate the measured data in nearly all cases. This is especially true for the control run which is assumed to reflect the natural variability of climate. This can be explained as a deficit in the model chain GCM–EDS (–HBV-D) which appears to reflect local conditions inaccurately, with an overestimation of precipitation and thus discharge conditions. On the other hand, deviations produced by the two downscaled scenario runs for the reference period lie within the range of assumed natural variability.

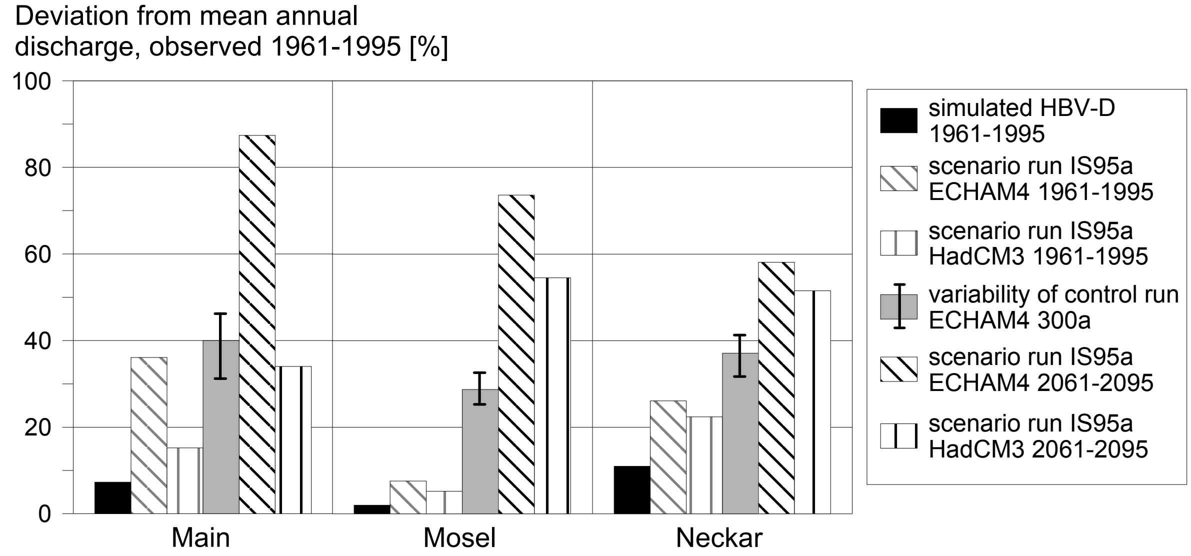


Fig. 3: Deviations (in %) between mean annual discharge determined by measurements and simulations using HBV-D with measured (black bars) and downscaled climate input, respectively. The database is composed of time series of daily measured and simulated discharge. The reference periods are the years 1961–1995 and 2061–2095. The data represented by the ECHAM4/OPYC3 control run refer to the period 1961–1995 (grey bars), to which the whole variability of the control run computed over 300 years (error bars) is added.

The two bars in Fig. 3 representing the scenario conditions for the period 2061–2095 show a distinct increase in comparison to mean observed discharge in the reference period. This represents the impact of the projected climate change. The comparison of scenarios derived by ECHAM4/OPYC3 and HadCM3 reveals that the data based on the first model produce far higher discharges. This can be attributed to the production of higher precipitation totals. The more moderate scenario conditions on the basis of the HadCM3 model are partly within the range of assumed natural variability (e.g. for the Main catchment in Fig. 3). This means that the projected increase in future mean discharge does not show a significant change from present conditions. Furthermore, the projected rises in mean discharge have to be considered against the model error in the reference period.

3.2 Climate change scenarios and changes in flood discharges

In a further step, the development of the mean flood discharge was examined. First, the annual maximum discharge per hydrological year was assembled from continuous discharge data so that annual maximum series (AMS) of flood discharge were available per sub-basin for measured and simulated discharge time series. The course of the mean flood discharge was examined by calculating moving averages within the AMS over a period of 30 consecutive years. For example, discharge simulations based on observed climate were available for a period of 35 years (1961-1995). By averaging over 30 years only five data points remain in this case (Fig. 4).

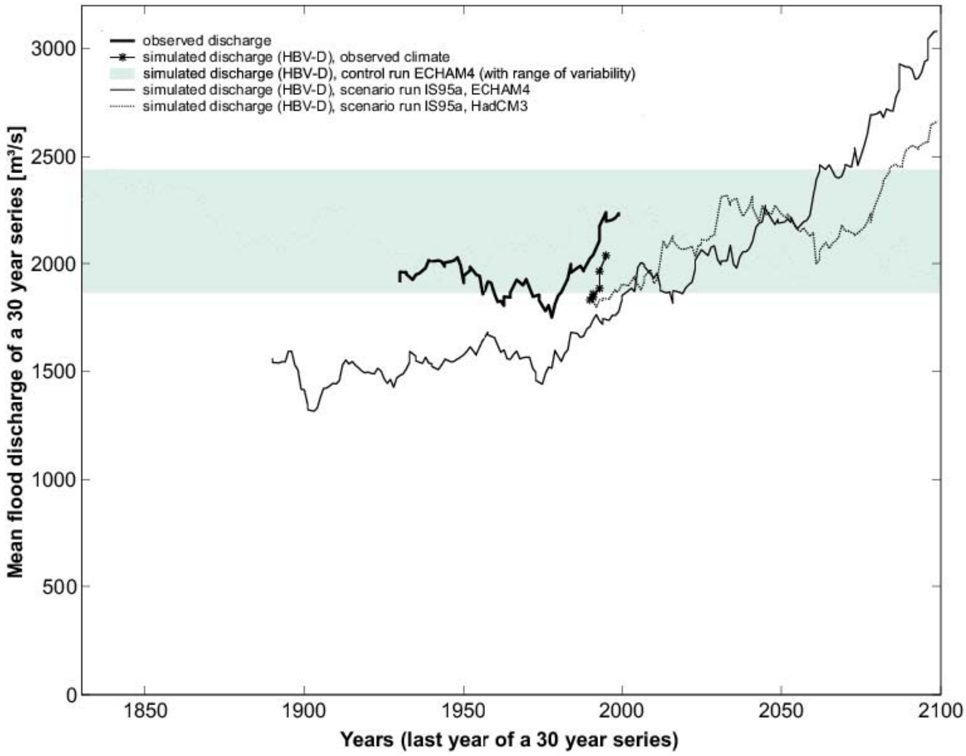


Fig. 4: Development of the mean flood discharge at the Cochem gauge (River Mosel). The data points represent running averages of annual maximum discharges over 30 consecutive years. The grey shaded box encloses the assumed natural variability as constructed using a 300-year ECHAM4/OPYC3 control run (explanation in the text).

The mean flood discharge from the AMS based on simulated discharge with observed climate/precipitation data only slightly underestimates the observed mean flood discharge (deviation of ± 10 %) whereas the application of the whole modelling chain – consisting of GCM, EDS and HBV-D – clearly underestimates the observed mean flood discharge during the whole observation period at the Cochem gauge (Fig. 4). Nevertheless, a dramatic increase in mean flood discharge is simulated with both GCMs for the 21st century, with the ECHAM4/OPYC3 scenario run giving a more pronounced rise. The courses of the scenario runs leave the upper margin of the assumed natural variability (grey shaded area in Fig. 4) between 2050 and 2080. For the representation of natural variability, moving averages of 30 consecutive years were calculated from the control run of ECHAM4/OPYC3 for the whole simulation period of 300 years. The minimum and maximum values of the moving averages frame the grey shaded area in Fig. 4. The mean of all moving averages was used as a representative value for the control run in Fig. 3 and Fig. 5.

Subsequently, the relative deviations from the observed mean flood discharge of the reference period 1961–1990 were calculated for each simulation run (Fig. 5). This serves for a better comparison of the orders of magnitude of model error, assumed natural variability and simulated projections of the mean flood discharge. In analogy to the mean discharge conditions (Fig. 3), the error of the hydrological model related to the representation of mean flood discharge totals to an acceptable maximum of ± 10 % for the reference period 1961–1990. For the same reference period, the error of the whole model chain is larger in all cases (up to ± 20 %). However, the total model error is almost within the range of the assumed natural variability of the ECHAM4/OPYC3 control run. As could be expected, this variability is far higher than the variability of mean discharge conditions given in Fig. 3.

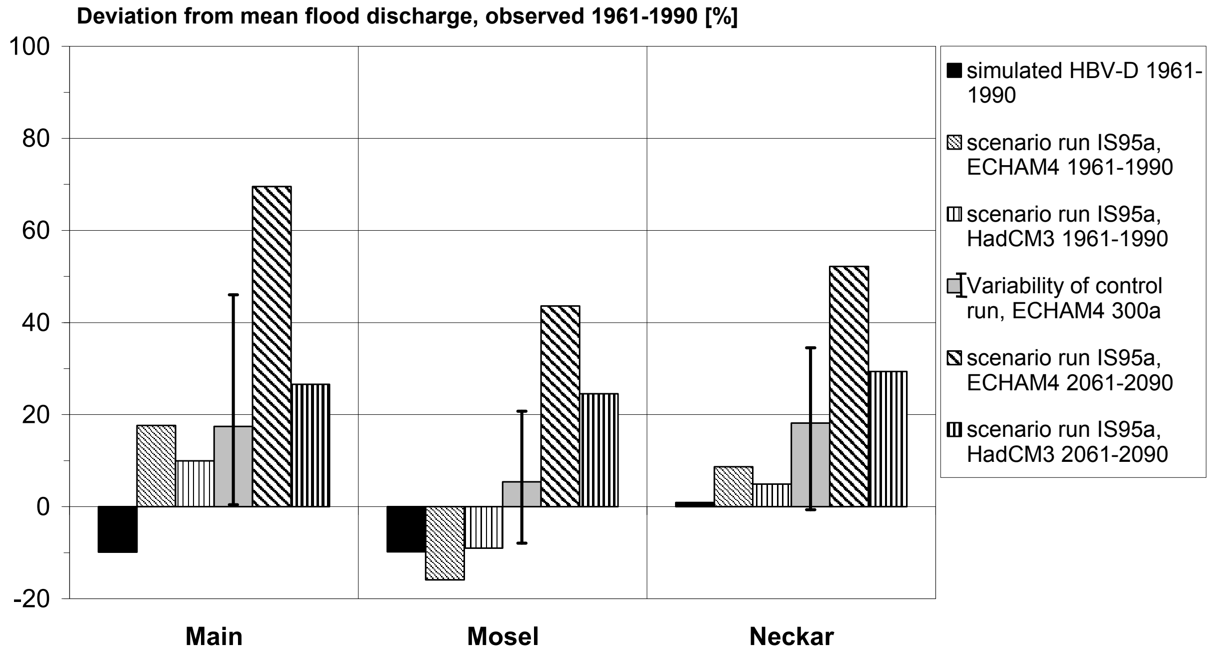


Fig. 5: Deviations (in %) between mean flood discharge determined by measurements and simulations using HBV-D with measured (black bars) and downscaled climate input, respectively. The database represents annual maximum series from daily measured and simulated discharge. Selected time intervals are the years 1961–1990 (reference period) and 2061–2090 (projection period). The data represented by the ECHAM4/OPYC3 control run refer to the reference period (light grey bars), to which the whole variability of the control run computed over 300 years (error bars) is added.

Furthermore, Fig. 5 shows that extremes tend to be underestimated in the reference period (e.g., for the Main and Mosel basins), whereas the mean discharge tends to be overestimated (e.g., for the Main and Neckar basins; see Fig. 3). This can be explained as follows: The analysis of the mean discharge considers all simulated daily discharges within a year or a 30 year series, whereas the analysis of the extremes builds upon only one (maximum) daily discharge value per year. It is therefore far more difficult to meet the extreme value statistics of the observed AMS than the mean discharge conditions.

For the projection period 2061–2090, the scenario run based on the ECHAM4/OPYC3 model clearly exceeds the upper margin of the assumed natural variability, which can be interpreted as a clear signal towards an increase in mean flood discharge under the scenario conditions. This is not true for the HadCM3 scenario run, which remains within the given range of assumed natural variability for most of the investigated sub-basins (Fig. 5). This means that the uncertainty of a future increase in mean flood discharge is remarkable when the results of both GCMs are considered to be of equal probability.

In a next step the whole distribution of flood discharges was examined. For this purpose, the Gumbel distribution was adapted to the AMS of the reference period (1961–1990) and the projection period (2061–2090) by the method of moments. Fig. 6 exemplarily shows for the Cochem gauge on the river Mosel that the uncertainty of a future increase in flood discharge rises with the return period of a flood event. For example, the magnitude of a 2–year flood is clearly higher for the projection period 2061–2090 in comparison to the reference period 1961–1990. This applies to both GCMs for floods of small return periods (i.e., up to approximately 10-year floods).

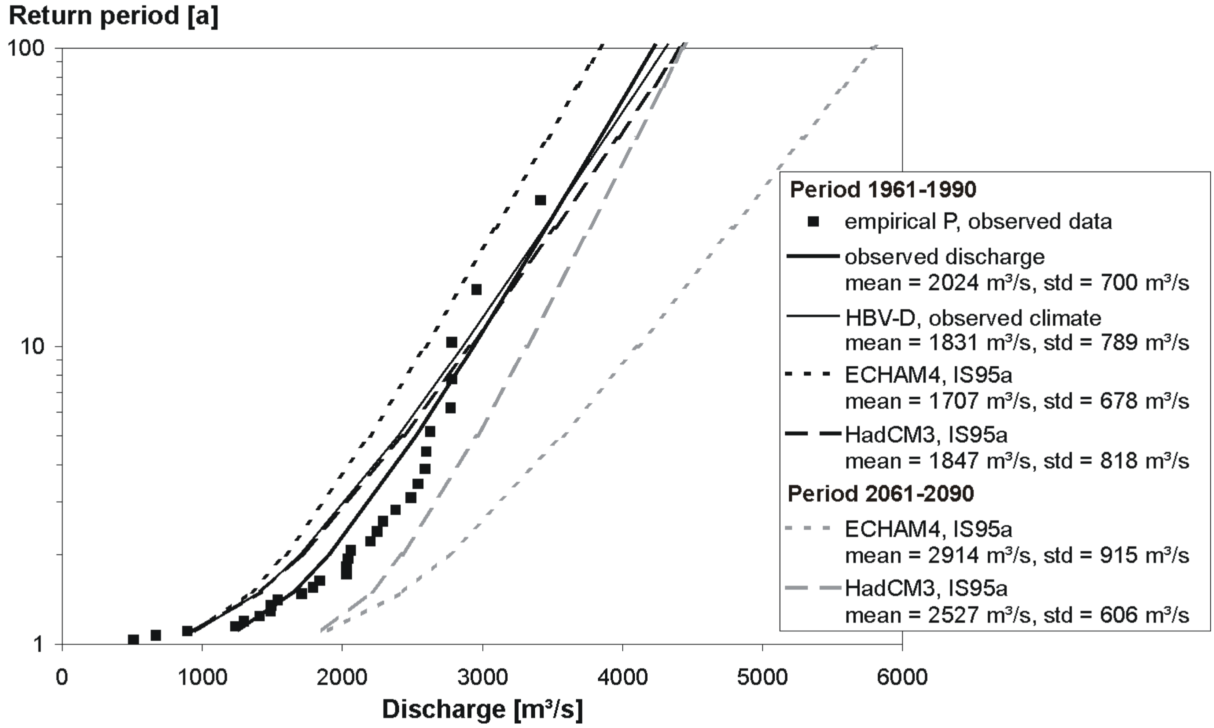


Fig. 6: Extreme value statistics (Gumbel distribution, method of moments) for the Cochem gauge on the river Mosel, applied to annual maximum discharge series from measured and simulated daily discharge data. Selected time intervals are the years 1961–1990 (reference period) and 2061–2090 (projection period).

For the projection period 2061–2090, the 100-year flood computed with the distribution based on ECHAM4/OPYC3 by far exceeds the respective value of the reference period. However, the flood of the same return period determined using the HadCM3 model projections nearly meets the 100-year flood of the reference period. Therefore, a projected increase in extreme flood discharge is even less significant and the related uncertainty is considerably higher than the simulated increase in mean flood discharge.

4 DISCUSSION AND CONCLUSIONS

In accordance with successful applications of the HBV model family in more than 40 countries (Bergström, 1995) this study proved that HBV-D is an appropriate tool for the reliable reproduction of discharge conditions in catchments of varying natural conditions. Since the model structure is not too complex and the principal input are time series of temperature and precipitation only, HBV-D can be applied for the simulation of long discharge time series (e.g. the control run spanned 300 years).

The underlying uncertainty within the application of climate change scenarios is clearly demonstrated. Since the present study could not include all sources of uncertainty, the given uncertainty bounds should be considered conditional. In principle, the uncertainty of climate change projections results from a cascade of individual uncertainties (Mitchell and Hulme, 1999) consisting of, firstly, the range of emission scenarios, secondly, the range of applied GCMs and, thirdly, downscaling methods like EDS. It is important to state in this context that the detailed information delivered by EDS on the local scale cannot be better than the information provided by the coarse spatial grids of the GCMs (Cubasch, 2001). Finally, the simulated, local climate variables are used to model discharge. Therefore, the hydrological model represents the fourth level of uncertainty.

Furthermore, Boorman and Sefton (1997) point out that climate impact studies also depend on the investigated area and the indices on which the study is focussed. For the scenario period a pronounced increase in discharge is projected by both GCMs over the whole investigated area. Considering the underlying model uncertainties, the magnitude of the projected increase is, however, highly uncertain. It was shown that the uncertainty of future projections increases from mean runoff (hydrological regime) up to extreme flood events such as the 100-year flood. Since the errors of the hydrological model were shown to be relatively small, the highest degree of uncertainty can be attributed to the coupled application of GCM output with the EDS method.

The projected development is reinforced by the trends already observed both in the Rhine catchment and beyond (see section 1). Therefore, we consider the application of climate change scenarios to be a useful part of hydrological research. However, the projections given by the simulations should not be mistaken for predictions. Keeping the described uncertainties in mind, scenarios are helpful for the evaluation of possible developments and for raising preparedness against adverse conditions, such as the increasing threat of floods or droughts.

Acknowledgements

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References can be found at the end of the thesis.

Paper 4: Influence of dike breaches on flood frequency estimation

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Abstract

Many river floodplains and their assets are protected by dikes. In case of extreme flood events, dikes may breach and flood water may spill over into the dike hinterland. Depending on the specific situation, e.g. time and location of breach, and the capacity of the hinterland to contain the flood water, dike breaches may lead to significant reductions of flood peaks downstream of breach locations. However, the influence of dike breaches on flood frequency distributions along rivers has not been systematically analysed. In order to quantify this influence a dynamic-probabilistic model is developed. This model combines simplified flood process modules in a Monte Carlo framework. The simplifications allows for the simulation of a large number of different scenarios, taking into account the main physical processes. By using a Monte Carlo approach, frequency distributions can be derived from the simulations. In this way, process understanding and the characteristics of the river-dike-floodplain system are included in the derivation of flood frequency statements. The dynamic-probabilistic model is applied to the Lower Rhine in Germany and compared to the usually used flood frequency analysis. For extreme floods the model simulates significant retention effects due to dike breaches, which lead to significant modifications of the flood frequency curve downstream of breach locations. The resulting probabilistic statements are much more realistic than those of the flood frequency approach, since the dynamic-probabilistic model incorporates an important flood process, i.e. dike breaching, that only occurs when a certain threshold is reached. Beyond this point the behaviour of the flood frequency curve is dominated by this process.

Keywords: flood frequency, dike breach, floodplain retention, probabilistic dynamic

This paper is currently in press:

APEL, H., B. MERZ, A.H. THIEKEN (2008): Influence of dike breaches on flood frequency estimation. – Computers and Geosciences (in press, already available as online first).

1 INTRODUCTION

The sound estimation of flood hazards is of particular relevance along large rivers where usually high damage potential has been accumulated over time, e.g. due to growth of urban areas or industrial sites. In many cases these areas are protected by river dikes. However, extraordinary floods may cause dike breaches and consequently high damages. For example, during the August 2002 floods more than 130 dike breaches occurred in Germany along the Elbe and its tributaries causing a total damage of approximately € 11.6 billion.

Depending on the characteristics of the river, the floodplains, the dikes and the characteristics of the dike breach, such as location and width of the breach, significant volumes of water may spill over into the dike hinterland, reducing the peak of the flood wave downstream of the breach location. This effect has been observed in the course of actual flood events (e.g. Engel, 2004), and it has been simulated for synthetic situations (e.g. Kamrath et al., 2006). Also the attenuation effect of flood plains has been studied in reaches without flood protection (Jothityangkoon and Sivapalan, 2003; Woltemade and Potter, 1994). However, the influence of dike breaches on the flood hazard situation along rivers has not been investigated systematically. This paper investigates particular influence for the Lower Rhine in Germany.

Flood hazard assessment is an essential basis for the development of flood mitigation schemes. Flood hazard is traditionally defined as the exceedance probability of potentially damaging flood situations in a given area and within a specified period of time. Flood hazard assessments for river reaches are usually based on a number of flood scenarios. Each scenario is associated with a certain exceedance probability P_E or return period T. For example, in many countries, such as United Kingdom, Germany, Italy, Spain, France, USA, Canada and New Zealand, the area affected by a 100-year flood plays an essential role for flood mitigation strategies. The proposed directive of the European Union on the assessment and management of floods requires two flood scenarios with return periods of 10 and 100 years, respectively, and an extreme scenario with a higher return period (EU, 2006). The same choice was made by the International Commission for the Protection of the Rhine: The Rhine-Atlas with a scale of 1:100000 provides an overview of the flood situation for the 10-year, the 100-year and an extreme event (ICPR, 2001).

Such flood hazard assessments consist of two steps: (1) estimating the T-year discharge along the watercourse, and (2) transferring the discharge values into inundation areas. The most widespread approach for the estimation of the T-year discharge along rivers is flood frequency analysis, i.e. the application of extreme value statistics to a record of observed discharges at the locations of interest (e.g. Stedinger et al., 1993). In many cases, at-site (local) frequency analysis is complemented by regional flood frequency analysis, using data from gauging stations that are supposed to have similar flood behaviour (e.g. Hosking and Wallis, 1997).

Flood frequency analysis suffers from various drawbacks, originating from insufficient data sets, and possible violation of the underlying assumptions of extreme value statistics. Discharge data series are hardly longer than 30-50 years. Consequently, an estimation of floods with return periods above 100 years is a wide extrapolation and hence highly uncertain. In those rare cases where longer time series exist, earlier periods might not be representative for today’s situation, and the basic assumptions of extreme value statistics, namely stationarity and homogeneity, might be violated.

Stationarity requires that the flood runoff randomly fluctuates in time with a constant pattern around a constant mean value. This implies that flood producing processes, e.g. rainfall regime or geomorphological characteristics of the catchment, do not change with time. Several studies have challenged the assumption of stationarity in flood frequency analysis due to climate variability (e.g. Jain and Lall, 2001; Milly et al., 2002; Pfister et al., 2004, Kingston et al., 2006) or human impact on hydrological processes (Helms et al., 2002, Lammerson et al., 2002, Pfister et al., 2004).

The assumption of homogeneity is violated if floods in the observation range and in the extrapolation range are caused or significantly influenced by different processes. Gutknecht (1994) discusses flood generation in small mountainous catchments and suggests that extreme flood events are caused by other meteorological, hydrological, hydraulic or geomorphological processes than frequent floods. The assumption of homogeneity may not hold either for floods that overtop and breach river dikes. Dike breaches might not have occurred during the observation period. Therefore, in the extrapolation range an additional process, namely retention of flood water due to dike breaches, appears that is not contained in the observed data set. Even if dike breaches had occurred in the observation period, the flood defence system would have been redesigned, possibly leading to significant changes in the river-flood system.

The simplest method for the second step of a flood hazard assessment, i.e. the transfer of discharge values in flooded areas, is based on the rating curves at the gauges and the floodplain DEM (Digital Elevation Model). The discharges for selected return periods T are converted to water levels via the rating curve. Further, the water levels between gauging stations are interpolated, and the T-year flooded area is obtained by intersecting the interpolated water level with the DEM. This simple method does not consider dike breaches. In some cases, it is applied to the situation with and without dikes, thus giving a rough idea of the flood defence effects of dikes. In flat lowland areas the intersection of DEM and water level at the gauge might produce unrealistic inundation extends, because the inundation area might be limited by the water volume available for flooding, an effect that is not considered by the intersection of water level and DEM.

More sophisticated methods use 1D or 2D hydrodynamic models to simulate the flooded area associated with a certain discharge value. Such approaches can include the effects of dike breaches. However, since the T-year discharge for certain river sections is taken from the flood frequency analysis, the effects of upstream dike breaches do not propagate, and they do not affect the flood frequency analysis at downstream gauges.

Besides the approaches that build on flood frequency analysis, deterministic, scenario-based approaches are used to investigate the effects of dike breaches (e.g. Alkema and Middlekoop, 2005, Kamrath et al., 2006). These approaches are based on simulation models that describe the processes of flood routing in the river (usually 1D hydrodynamic model), dike breaching and flooding of the hinterland (usually 2D hydrodynamic model). They are able to consider the downstream effects of dike breaches. However, since they only consider deterministic scenarios, it is not clear how this information can be incorporated into flood frequency statements. Further, they are computationally very demanding, which limits the possibility of simulating many scenarios.

The aim of this paper is to investigate how flood frequency distributions along river reaches are influenced by dike breaches. We start from the hypothesis that, under extreme hydrological loading, river dike breaches might significantly influence the shape of the flood frequency distribution. To this end, we extend a dynamic-probabilistic model that has been developed and applied to the Lower Rhine by Apel et al. (2004, 2006). This approach combines simplified flood process models in a Monte Carlo framework. The simplifications allow us to simulate a large number of different scenarios, taking into account the main physical processes. By using a Monte Carlo approach, frequency distributions can be derived from the simulations. The model results are compared to the usual approach for flood hazard assessment along rivers.

2 STUDY AREA

The investigation area in this study is a reach of the Lower Rhine in Germany between gauge Cologne (Rhine-km 688) and gauge Rees (Rhine-km 837) near the German-Dutch border (Figure 1). The two major tributaries within the reach are the rivers Ruhr and Lippe. Their input to the system is considered in the modelling approach.

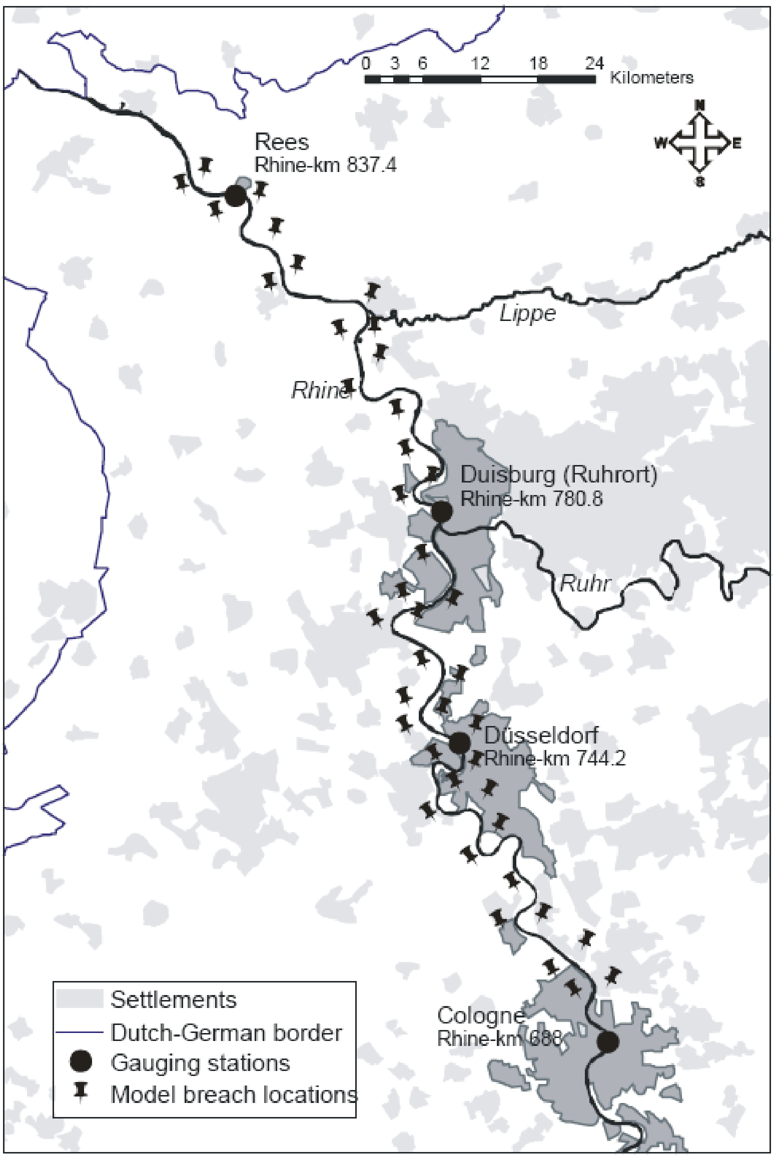


Fig. 1: The investigation area Lower Rhine between Cologne and Rees.

The stretch of the river represents a typical large lowland river with wide meanders and is almost completely protected by dikes on both sides. The total length of the embankments at the Lower Rhine amounts to 330 km and the safety levels vary between a 20-year flood for small summer dikes and a 500-year flood for the main structures (ICPR, 2001). The hinterland behind the dikes has a large damage potential due to many densely populated settlements and industrial areas. Assuming an extreme event (i.e. approximately a 500-year flood) the ICRP (2001) estimates an area of 1356 km² at risk of inundation along the Lower Rhine with direct economic losses of € 20333 million. However, according to MURL (2000a) the inundated area is reduced to 420 km² by the embankments.

All the dikes in the reach were rebuilt in the last decades according to the engineering state of the art. They are zonated dikes with an impermeable surface layer at the water side connected to an impermeable basement, and a draining permeable layer at the land side often accompanied with a basement drainage. This construction type minimises the probability of dike failure due to piping, i.e. internal erosion, seepage or basement failures.

The flow regime of the River Rhine is dominated by snowmelt and precipitation runoff from the Alps in the summer months, and further downstream by precipitation runoff from the uplands of central Germany and neighbouring countries in winter (Disse and Engel, 2001). The mean daily discharge amounts to 2087 m^3/s at gauge Cologne (data from 1880 to 2004) and to 2284 m^3/s at gauge Rees (data from 1930 to 2000). Little seasonal variation enables year-round navigability (Disse and Engel, 2001).

At the Lower Rhine, floods frequently occur during winter and early spring. In the annual maximum discharge series from 1880 to 2004 only 7 % of the annual maxima (9 events) at the gauge Cologne occurred in summer (May – September) whereas 85 % took place between November and March.

Severe flood events occurred in December 1993 and January 1995. Both events originated in the uplands of the Middle and Lower Rhine where heavy precipitation fell on saturated or frozen soil resulting in high runoff coefficients (see Chbab, 1995, Fink et al., 1996). In Cologne, the maximum water levels amounted to 10.61 m (~ 10700 m^3/s) in 1993 and 10.69 m (~ 10800 m^3/s) in 1995. In 1995, a damage of € 33.23 million occurred in Cologne and was only about half of that associated to the 1993 flood (Fink et al., 1996). This effect was also observed in other municipalities and was mainly attributed to improved preparedness and disaster management (Wind et al., 1999).

3 DYNAMIC-PROBABILISTIC APPROACH FOR FLOOD HAZARD ASSESSMENT

3.1 Outline of the approach

The dynamic-probabilistic approach is a set of modules, each representing a component in the flood processes of the study area:

- Hydrological input at Cologne:
  At gauge Cologne, the upstream boundary of the system, the input into the system in terms of flood peak and shape of flood hydrograph is described.
- Superposition of flood waves of Rhine and of major tributaries:
  The behaviour of the main tributaries Lippe and Ruhr is of importance for the flood situation in the Lower Rhine. High flood peaks of Lippe and Ruhr at times of high

discharge values in the Rhine aggravates the flood situation of the Lower Rhine. Therefore, the interplay of flood peaks and hydrograph shape between the Rhine and the tributaries is taken into account.

- Hydraulic transformation:
  This module calculates water levels in the river reach for given discharges.
- Dike failure due to overtopping and outflow through dike breach:
  This module tests whether dike segments are overtopped. In this case, a two-dimensional dike fragility curve is applied which estimates the probability of a dike breach under a given hydrological load. If a breach occurs, a breach width is selected and the outflow into the hinterland is determined, which corresponds to a decrease in flood volume downstream of the breach location.

For each of these processes simple and computationally efficient models were developed. They are based on several pre-processing works. With the exception of the module 'Hydraulic transformation', all modules contain probabilistic elements. This approach reflects the inherent variability of flood processes and our inability to deterministically describe such processes as the superposition of flood peaks of the Rhine and its tributaries. The modules are linked and embedded in a Monte Carlo simulation framework. Each Monte Carlo run generates a single flood event resulting in an ensemble of flood events from which empirical probabilities can be derived.

The following sections give a short description of the modules. A more detailed description can be found in Apel et al. (2004, 2006). The module 'dike failure due to overtopping and outflow through dike breach' is described in detail, since this module was extended to account for a quasi-continuous mode of dike failure along the complete study area. The model version of Apel et al. (2004, 2006) was restricted to two dike breach locations only.

3.2 Hydrological input at Cologne

For each flood event that is generated by the modelling system we need the input into the river system at its upstream boundary, i.e. at the gauge Cologne/Rhine. Since the retention effects of dike breaches are studied, the complete hydrograph at gauge Cologne has to be generated for each event. This procedure is divided into two steps. In the first step a flood peak value is generated, and in the second step a hydrograph is assigned to this peak value.

The flood peaks are estimated by means of a flood frequency analysis, based on the observation data at gauge Cologne. It is well known that the choice of the distribution function may significantly influence the result of flood frequency analysis. Different types of distribution functions can be applied, usually leading to very different flood quantiles in the extrapolation range. From the spectrum of distribution functions used in flood frequency analysis, the following set of functions representative for the different classes of extreme value distribution functions was chosen: Gumbel, LogNormal, Weibull, Pearson III and Generalised Extreme Value (GEV) (Stedinger et al., 1993). This subjective selection was performed under the assumption of no a priori knowledge of the most appropriate function type for the region and with the intention to cover the functions frequently used as well as all classes of distribution function types.

The functions are fitted to the data sets by the method of moments, except for the GEV where L-moments are used. The goodness of fit of the different functions is assessed by a maximum likelihood method (Wood and Rodriguez-Iturbe, 1975). Based on this fitting criterion, a composite distribution function is derived by weighing the different distribution functions according to Wood and Rodriguez-Iturbe (1975). Figure 2 shows the fitted distribution functions to the data set of Cologne along with the maximum likelihood weights.

The annual maximum discharge series of the gauge Cologne for the period 1961-1995 is used, although much longer series exist. Extensive river training works and retention measures, the construction of weirs along the Upper Rhine, and effects of climate variability suggest significant changes in the flood behaviour during the first half of the 20th century (Lammersen et al., 2002, Pfister et al., 2004). Therefore, former observations might not be representative for the current state of the river system.

To obtain hydrographs, typical normalised hydrographs are extracted from the discharge data series: For every year the maximum flood event was extracted from the hourly discharge series and normalised to flood peak discharge and time to peak discharge. The resulting 35 normalised flood hydrographs were subjected to a cluster analysis yielding seven characteristic flood waves (i.e. seven clusters). The clusters can be grouped into short single peaked, short waves with small peaks preceding maximum and long multiple peaked flood events (Apel et al., 2004). The normalised hydrographs are assumed to be independent from the return periods. However, each normalised flood waves is assigned with an occurrence probability, which is equal to the proportion of the number of flood events in the respective cluster to the total 35 flood events, thus indicating the probability of the annual maximum flood to belong to a single cluster. These occurrence probabilities are not to be confused with return periods of flood peak discharge.

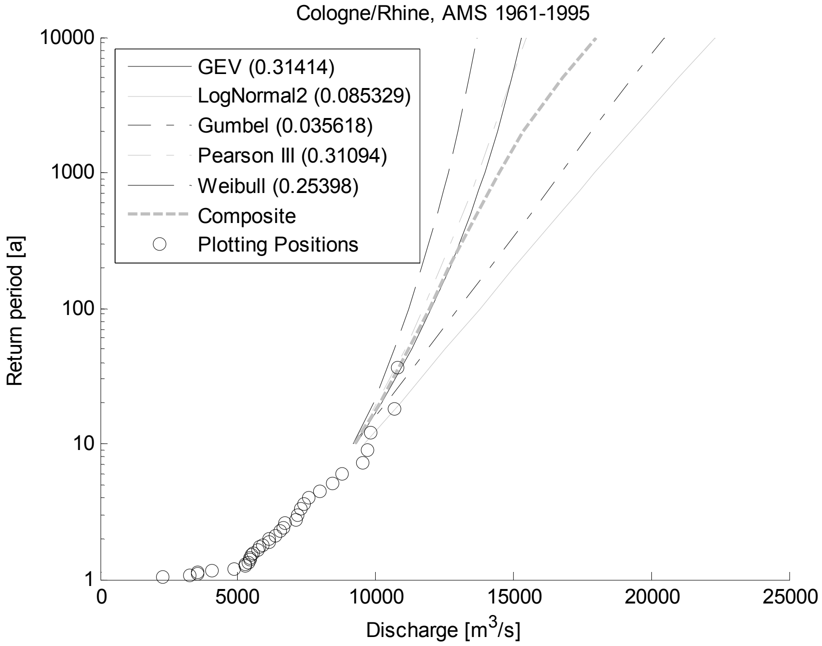


Fig. 2: Fit of five different extreme value distributions to the annual maximum discharge series of Cologne from 1961-1995 and the composite distribution function constructed by the likelihood weights given for each function in the legend.

3.3 Superposition of flood waves of Rhine and tributaries

The interplay between floods in the main river and floods in the tributaries is considered by a correlation analysis of the annual maximum discharges of the main river and the corresponding events in the tributaries. The analysis shows that a rather tight linear correlation between the discharge peaks of the Rhine and the peaks of Lippe and Ruhr exist. This correlation in combination with the confidence intervals of the linear regression is used to randomly generate a peak value for the tributaries, given the peak value of the Rhine (Apel et al., 2004).

For each hydrograph cluster of the Rhine, the corresponding mean shapes of the hydrographs of the tributaries are derived, based on the annual maximum data of gauges Hattingen/Ruhr and Schermbeck I/Lippe for the period 1961-1995. In the Monte Carlo simulation for each generated flood event the mean hydrograph of the same cluster as the main river is chosen at the tributaries, thus retaining the dependency of the flood events in main river and tributaries. This dependency is caused by similar flood generating processes, i.e. high precipitation events in the uplands of the Middle and Lower Rhine (cf. section study area). Figure 3 shows the superposition of the synthetic main and tributary flood events for all seven flood types. It can be seen that the flood waves of main river and tributaries show similar characteristics in all clusters thus indicating the identical generating processes mentioned above. However, the peaks do not overlay. In some cases the tributaries precede the peak in the main river, in others they follow. This can be interpreted as a result of different cyclone pathways causing the different precipitation fields in the uplands.

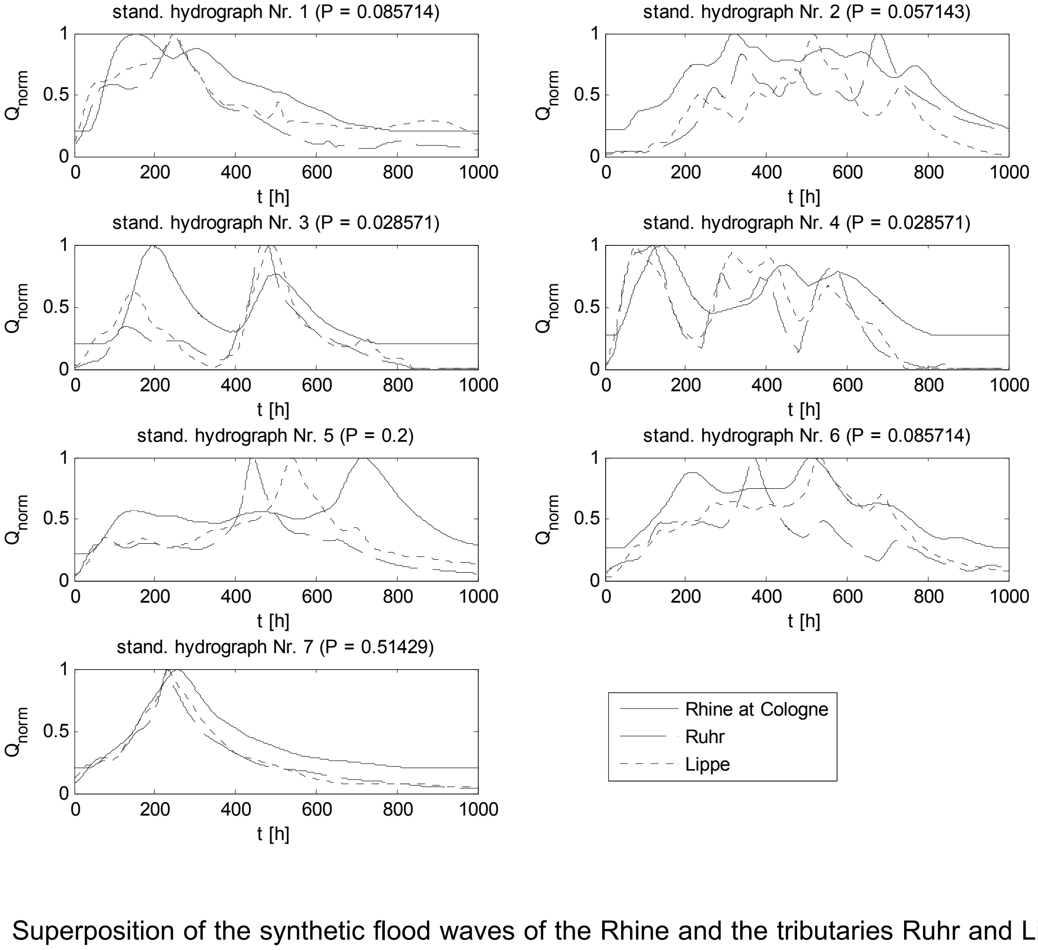


Fig. 3: Superposition of the synthetic flood waves of the Rhine and the tributaries Ruhr and Lippe for each flood type identified in the cluster analysis. The flood waves are scaled in time, but normalised in flood peaks to show the delay of flood peaks. P indicates the probability of a flood to belong to the respective clusters.

3.4 Flood routing and hydraulic transformation

1D-hydrodynamic simulations of flows in the investigated reach have shown that the flood peak attenuation and the stretching of the flood wave in the reach are negligible. Figure 4 shows the flood wave of the flood of December 1993, which is hardly modified within the 160 km under study. The increase in the flood peak flow can be attributed to the tributary inputs, even for the sub-reach between Cologne and Düsseldorf, where minor tributaries join the Rhine. This results in an increase in flood peak flow of 72 m³/s in the sub-reach, which is equivalent to an increase in stage of 3 cm at gauge Düsseldorf. This minor flood peak deformation, which is below the accuracy of the digital elevation model and the surveyed dike elevations, can be assumed for the complete reach, because no major changes in the river morphology occur further downstream. Therefore the routing effect is neglected in this study, which reduces the computational effort considerably.

However, in order to obtain discharge stage curves for every breach location (cf. section 3.5) the 1D-hydrodynamic model HEC-RAS (Brunner, 2002) with cross sections every 500 m was adapted to the Lower Rhine. Using a simulation of the flood event of 1995, the discharge stage curves were extracted from the simulation results at the appropriate cross sections.

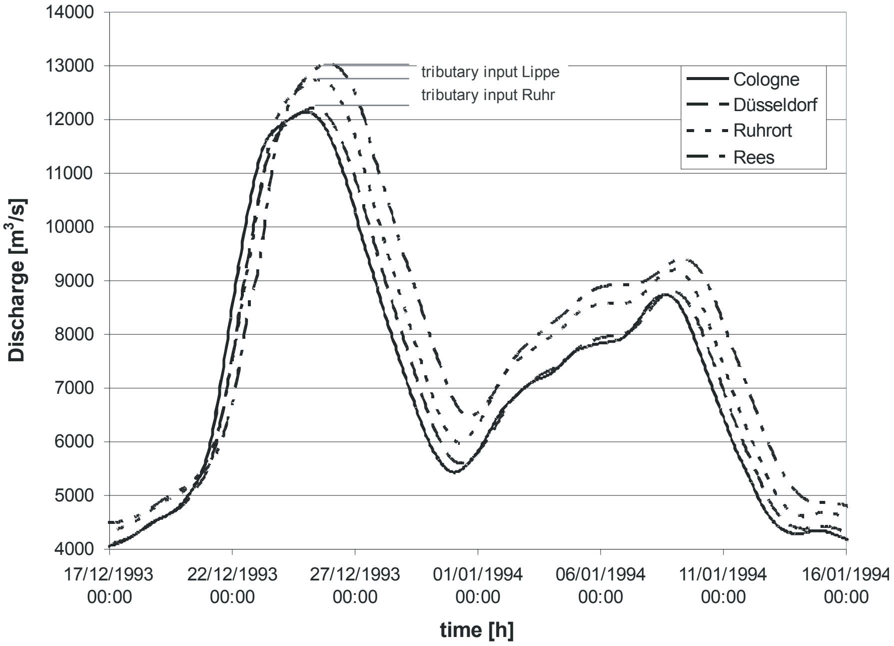


Fig. 4: Flood wave attenuation and translation for the flood event of 1993 in the study reach.

3.5 Dike failure due to overtopping and outflow through dike breach

Breach locations This module tests whether dikes are overtopped and possibly breach for a given flood wave. In case of breaching, it calculates the outflow in the hinterland and the reduction of the flood wave in the main river.

Almost the complete river reach in the study area is accompanied by dikes, i.e. there are almost 330 km of dikes. In principle, a dike breach could occur at each point along the dike lines. A continuous test for dike breaching would require an enormous amount of CPU-time, especially in a Monte Carlo framework. Therefore, a quasi-continuous scheme was developed which is supposed to reduce the potential dike breaching locations to a manageable number. The scheme is comprised of the following steps:

1. 2D-inundation simulations are performed every kilometre on both sides of the river for a fixed breach width of 100 m and a breach depth reaching the basement of the dike. A constant breach outflow is assumed approximating the outflow in case of river water levels at dike crest height. The breach outflow is calculated with a standard formula for broad crested weirs.
2. The inundated areas of the breaches at different locations are compared and grouped according to the similarity of the inundation areas. Each of these groups represents a model breach location, where the model breach is located in the midpoint of the dike section of the group.

By this procedure 41 model breach locations were identified on both sides of the river along the complete reach (Figure 1). For the 2D-inundation simulations, a raster model based on the diffusion wave analogy, an approximation of the full St.-Venant equations, was used. The approach is identically to the floodplain inundation part of LISFLOOD-FP developed by Bates and de Roo (2000). The simulations were performed on the basis of a Digital Elevation Model with grid size of 50 m using the adaptive time-stepping given by Hunter et al. (2005). The roughness parameterisation was derived on the basis of the CORINE land use data with parameters assigned to each land use class according to published values (Werner et al., 2005; Chow, 1973).

Dike failure mechanism and probability The fragility surface results from the comparison of the erosional stress inflicted on the dike surface by the overtopping flood wave and the resistance of the dike. The stress is described by the actual discharge q_a overtopping the dike. The calculation of q_a is performed with a broad crested weir formula especially modified for dike overflow (Kortenhaus and Oumeraci, 2002). The calculation of the resistance q_{crit} follows the approach of Vrijling (2000) and is based on data published in Hewlett et al. (1987). Following these considerations the dike breaches, if $q_a > q_{crit}$ with

$$q_a = A \cdot dh^{3/2} \qquad \text{(Kortenhaus and Oumeraci, 2002)} \qquad (1)$$

$$q_{crit} = \frac{v_c^{5/2} \cdot k^{1/4}}{125 \tan \alpha_i^{3/4}} \qquad \text{(Vrijling, 2000)} \qquad (2)$$

and

$$v_c = \frac{(3.9117 + 1.5 \cdot (f_g - 1))}{1 + (0.8575 - 0.45 \cdot (fg - 1)) \cdot \log_{10}(t_e)} \qquad (3)$$

where A [m²/s] is a summary parameter representing the geometric features of the dike (see Kortenhaus and Oumeraci, 2002 for details), dh [m] is the difference between the water level and the levee crest, v_c [m/s] is the critical flow velocity, α_i [deg] the angle of the inner talus, k [m] the roughness of the inner talus, f_g [ ] a parameter describing the quality of the turf covering the dike, and t_e the overflow duration [h]. Formula (3) is parameterised on the basis of experimental data given in Hewlett et al. (1987), with f_g = 1 representing average turf conditions, f_g = 0.5 poor and f_g = 1.5 good turf conditions. Figure 5 shows the fit of (3) to the data.

If we had perfect knowledge of the parameters that influence the erosional stress and the dike's resistance, the comparison of q_a with q_{crit} would decide whether the dike breaches or not. Since dike parameters are time- and space-variable and not perfectly known, they are described by probability distribution functions, based on data given by Vrijling (2000) for Dutch river dikes. For a certain dike breach location, the probability of breaching $P(B \mid (dh, t_e))$ for a given couple of overtopping height *dh* and overtopping duration t_e is calculated by randomly generating dike parameters from the respective distributions (10^4 samples in this study) and evaluating the quantity $q_a - q_{crit}$. $P(B \mid (dh, t_e))$ equals to the relative frequency of failures. This procedure is repeated for the complete domain of *dh* and t_e, and for three distinct values of f_g (0.5, 1, and 1.5). In this way fragility surfaces for each dike breach location were constructed as exemplarily shown in Figure 6.

During each run of the dynamic-probabilistic model each breach location is tested for failure in downstream order. Given the current combination of *dh* and t_e, the fragility surface yields the probability of failure. In our calculation we assumed an average quality of the turf surface, i.e. $f_g = 1$, for all breach locations.

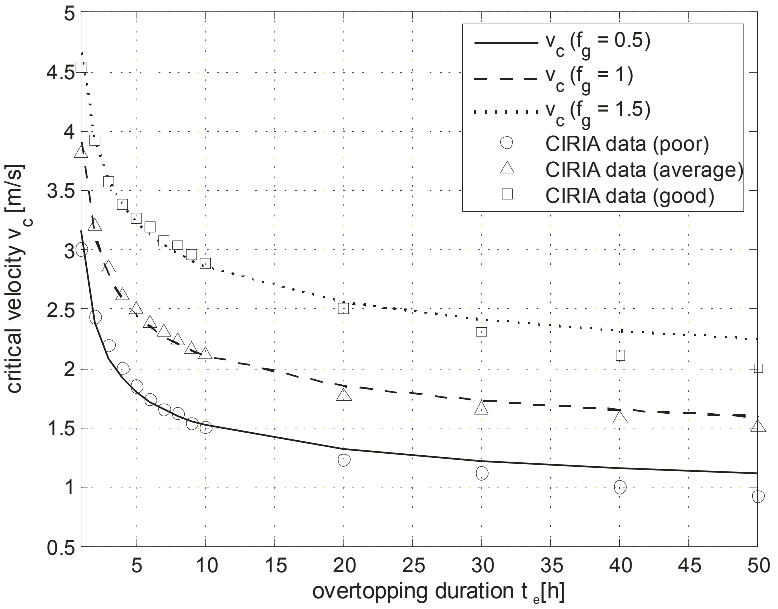


Fig. 5: Fit of the empirical formula for the critical dike overflow velocity (3) to experimental data published by Hewlett et al. (1987), Goodness of fit: RMSE = 0.06844 m/s, coefficient of determination R^2 = 0.954.

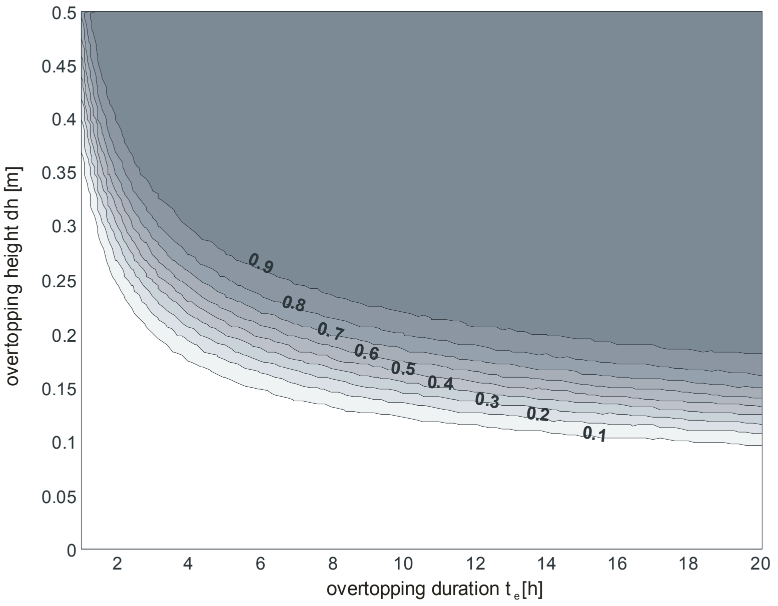


Fig. 6: Conditional failure probabilities (fragility surface) for breach location 1 depending on overflowing duration and overtopping height.

Breach width The width of dike breaches strongly influences the spill-over of water into the hinterland. The breach width depends on the actual flow situation during the breach, and on the construction material and geometric properties of the dike. Since there is not enough information to quantify the relation between breach width, dike properties and flow situation, the breach width is assumed as a random variable. Its distribution is based on an evaluation of historical dike breaches at the Rhine in 1882-1883 (Merz et al., 2004). This data set comprises 14 breaches, with a mean breach width of 70.3 m and a standard deviation of 31.5 m. We further assumed a normal distribution of the breach widths. However, we constrained the randomised breach widths to a lower bound equalling the smallest observed breach width of 34 m and an upper bound of 200 m in order to keep the randomised breach widths within a reasonable range.

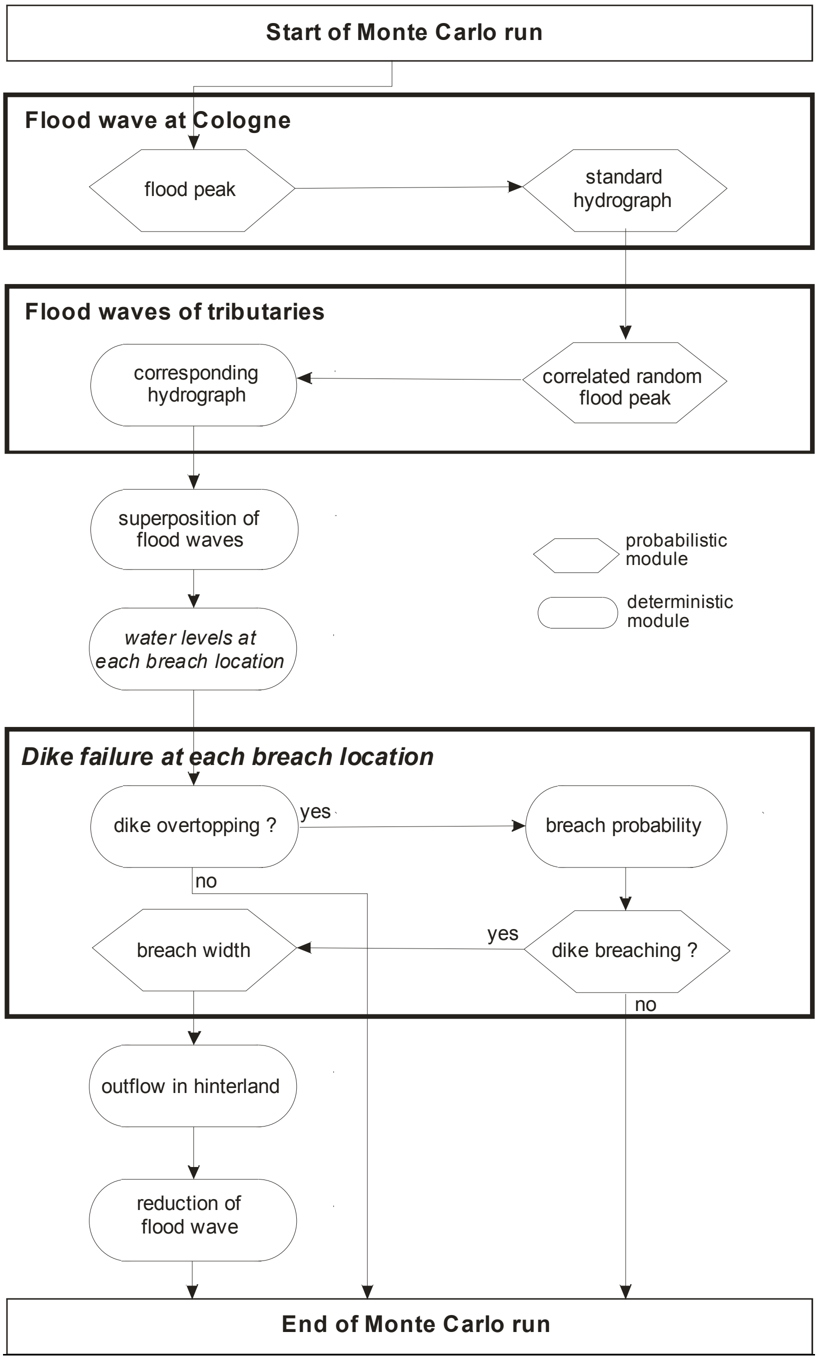


Fig. 7: Scheme of the dynamic-probabilistic model for a single Monte Carlo run.

3.6 Monte Carlo Simulations

The four modules are linked in a Monte Carlo simulation. Figure 7 shows the outline of this procedure. Each Monte Carlo run is equally likely and comprises the:

- generation of a flood wave at Cologne,
- generation of tributary flood waves, conditioned on the flood wave in the main river,
- transformation of discharges into stages at each model breach location,
- test for overtopping at each model breach location,
- in case of overtopping: calculation of the breach probability conditioned on the actual overtopping height and duration using the fragility surfaces, and random determination of breaching (based on the calculated breach probability and a randomly drawn number),
- in case of breaching: generation of breach width,
- in case of breaching: calculation of flow into the hinterland and reduction of the flood wave in the main river,
- superposition of the tributary flood waves at the appropriate routing nodes.

This procedure is repeated 10^5 times, yielding 10^5 synthetic flood events. In empirical tests this number of Monte Carlo runs proved to yield stable results up to return intervals of 10^4 years. Since the event generation is based on annual maximum discharge data, the resulting discharge and damage series are considered as annual maximum series. Thus annual exceedance probabilities and return periods can be derived from the generated data sets.

4 RESULTS

In 150 of 10^5 model runs dike breaches occurred. All breaches were concentrated at the first six model breach locations, i.e. at the upstream end of the river system. The hinterland of these dike segments can contain large flood volumes. Therefore, these breaches reduce the flood waves even in an extreme event such that further downstream the dikes are not overtopped and hence the considered breach mechanism is not triggered. The retention effect due to dike breaching is thus well reproduced by the model system.

Figure 8 shows the effect of the dike breaches on the discharges associated to events with selected return intervals along the river reach. For the gauging stations downstream of Cologne (Düsseldorf, Ruhrort, Rees) the dynamic-probabilistic model yields lower discharges for rare events in comparison to the flood frequency analysis described in section 3. The reduction is particularly dramatic for the 5000-year flood. The lower discharge values for large events are a consequence of the dike breaches and the flood attenuating effect of the inundation of the hinterland. For lower return intervals (100, 200, 500 years) the dynamic-probabilistic model yields slightly larger discharges than the flood frequency analysis, which results from the different shapes of the distribution function of the downstream gauging stations in comparison to Cologne.

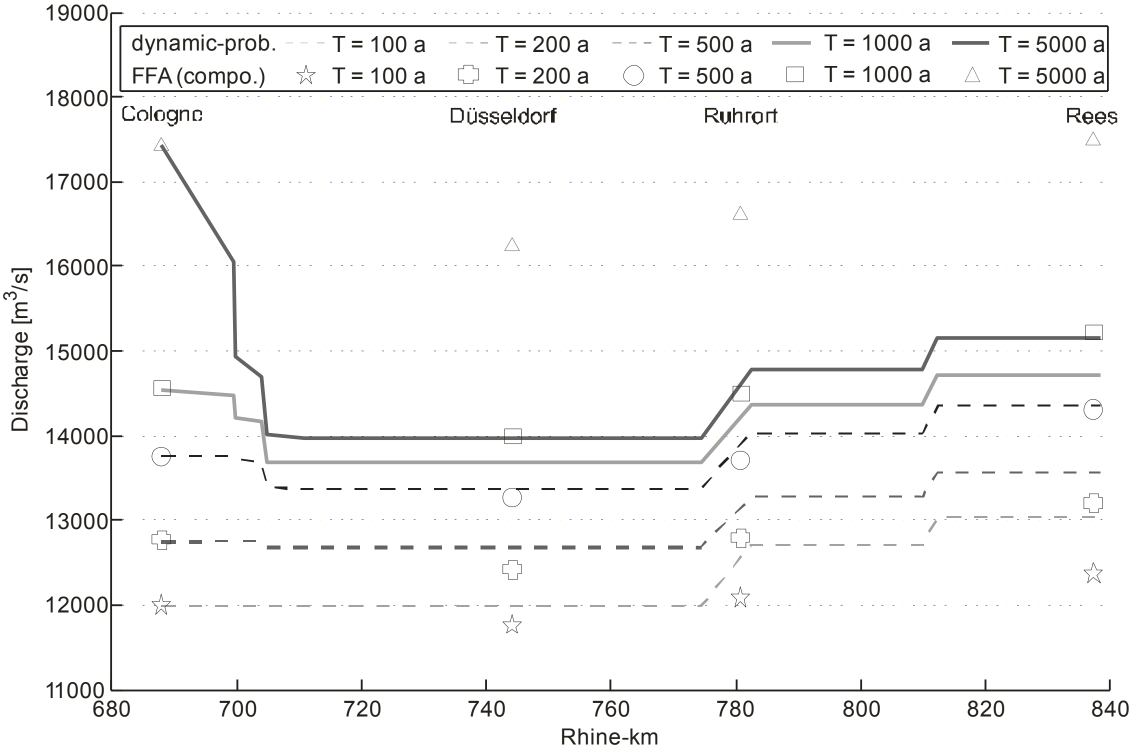
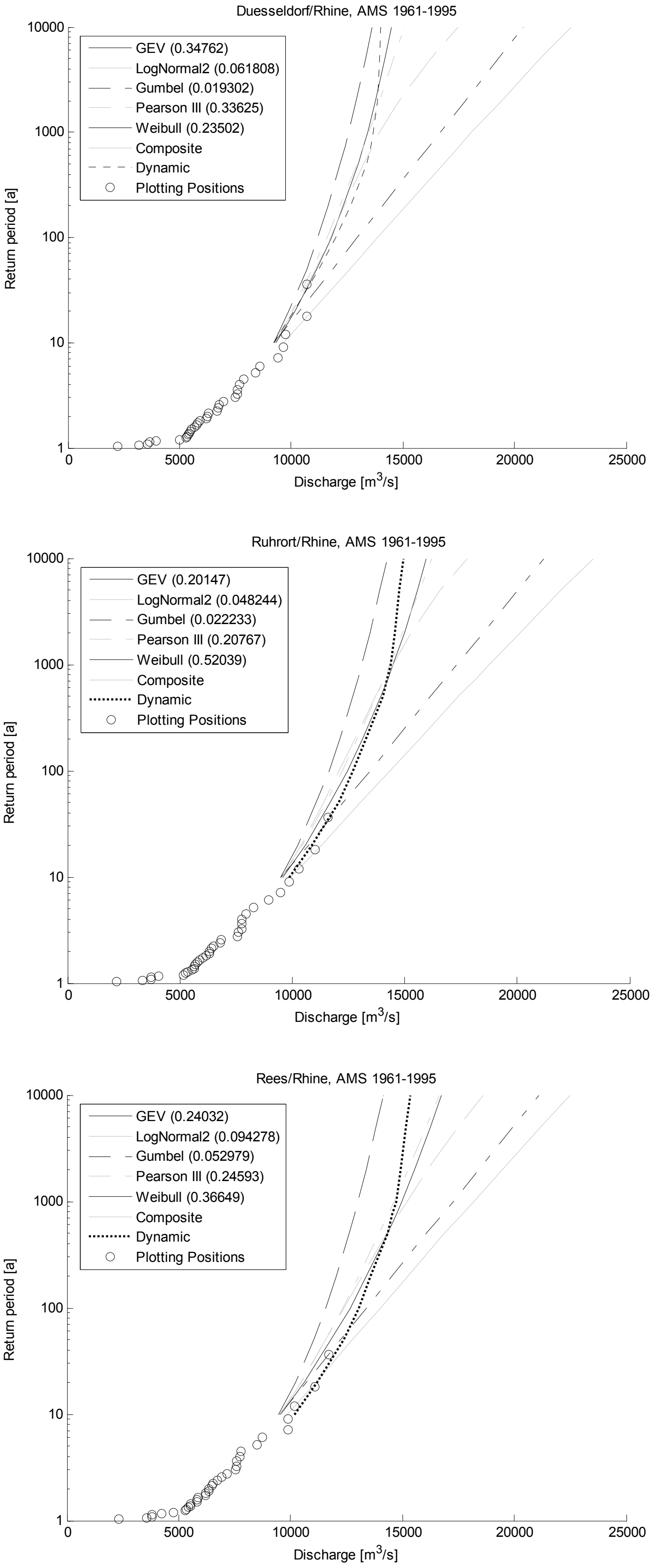


Fig. 8: Plot of discharges for selected return intervals along the river reach. The solid lines represent the results of the dynamic-probabilistic model, the markers the results of extreme value analysis (composite function) for the gauging stations.

These effects are also illustrated in Figure 9 showing the flood frequency curves for Düsseldorf, Ruhrort and Rees. For each station the frequency analysis calculated with different distribution functions and the composite function are plotted along with the results obtained with the dynamic-probabilistic model. It can be seen that with the exception of the Weibull function none of the frequency curves obtained by flood frequency analysis reflect the retention effect caused by dike breaches in contrast to the result of the dynamic-probabilistic model. For large and rare events the dynamic-probabilistic model predicts discharges asymptotically approaching maximum discharge. This discharge can be regarded as the probable maximum flood (PMF).

The Weibull function shows a similar characteristic as the derived flood frequency curve. However, the discharges predicted for extreme events are very low: Even for return intervals larger than 10000 years the discharge stays below the dike crests, i.e. no floodplain inundation will occur in this case. This means that the asymptotical behaviour of the frequency curve does not describe the actual peak attenuating process. On the contrary, in this case it rather shows the inappropriateness of the function despite the comparatively high likelihood weights (cf. Figure 9).



Duesseldorf/Rhine, AMS 1961-1995

Ruhrort/Rhine, AMS 1961-1995

Rees/Rhine, AMS 1961-1995

Fig. 9: Comparison of extreme value statistics for the gauging stations Düsseldorf, Ruhrort and Rees with the result of the dynamic-probabilistic model. The numbers in the legend give the likelihood weights associated to the five basic distributions, which were use for the construction of the composite function.

In order to test the plausibility of the model results, the model estimates for the 1000-year flood at the gauges Düsseldorf and Rees (downstream of Cologne) as well as the corresponding estimates on the basis of a flood frequency analysis with a log-normal distribution were compared with observed outstanding flood events in Germany and other European countries. The comparison is based on specific peak specific discharges (Figure 10-A). For this purpose the data base of Stanescu (2002) was extended by data from Herschy (2003) and by various discharge data from the flood events that occurred recently, i.e. in 1997, 1999, 2002 and 2005, in Germany.

Figure 10-A illustrates that there is an upper bound of the specific discharge that declines with increasing catchment area. Both the model estimates and the estimates of the log-normal distribution exceed the specific flood discharges observed in Germany at comparable gauges. However, Figure 10-B illustrates that higher specific discharges occurred in other European catchments of a similar size (e.g. Danube, Don, Wisla, Odra). While the estimates of the dynamic-probabilistic model for the 1000-year flood at the gauges Düsseldorf and Rees are in the range of the observed specific discharges, the estimates of the log-normal distribution are the utmost margin of the data. This indicates that the dynamic-probabilistic model yields more realistic estimates of extreme flood discharges in comparison to a standard extreme value statistics approach.

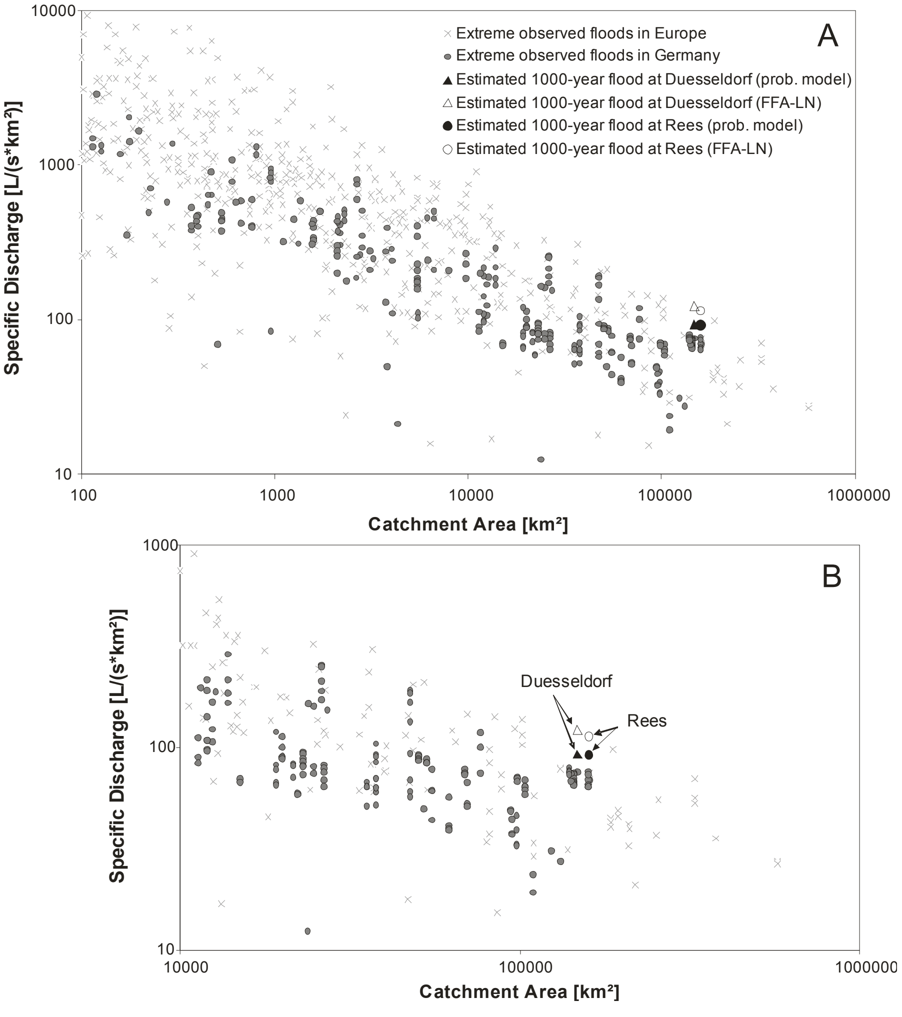


Fig. 10: Comparison of estimates for the 1000-year flood at the gauges Düsseldorf and Rees with observed outstanding flood events in Germany and other European countries (data from Stanescu, 2002, Herschy, 2003 and various gauging stations in Germany).

5 CONCLUSIONS

The influence of dike breaches on the flood hazard situation along rivers with dikes that protect large former flood plains has not been systematically examined. Flood frequency analysis is usually not suited for such an analysis, since extreme events are not sufficiently represented in the data sample, or since the assumption of flood frequency analysis are violated. Therefore, a dynamic-probabilistic model has been developed that links simplified modules describing the processes of the river-dike-flood plain system within a Monte Carlo framework. In this way, it is possible to derive "process-oriented" flood frequency distributions.

The model is applied to the Lower Rhine in Germany. The results agree well with the usually used approach, i.e. the flood frequency approach, for flood events where no dike breaches occur. However, for extreme floods (e.g. 1000-year flood) dike breaches lead to large retention effects altering the flood frequency curve. The resulting probabilistic statements are much more realistic than those of the flood frequency approach, since the dynamic-probabilistic model incorporates an important flood process that only occurs when a certain threshold is reached. Above this threshold the behaviour of the flood frequency curve is dominated by dike failures and floodplain inundation. The dynamic-probabilistic model acknowledges the fact that large floods are not large versions of small floods – an assumption that is implicitly built into flood frequency analysis.

The proposed method is principally transferable to any other diked river reach. However, the necessary preprocessing works are quite intensive in terms of data demand and computation time, while the actual model is very computational efficient. Therefore we recommend using the model in another area for multiple purposes, e.g. the derivation of derived flood frequencies and risk assessments for different development scenarios, in order to optimise the benefits gained by the model.

References can be found at the end of the thesis.

SECTION II:

FLOOD LOSSES – ANALYSIS AND MODELLING

Paper 5: Flood damage and influencing factors: New insights from the August 2002 flood in Germany

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Abstract

In the aftermath of a severe flood event in August 2002 in Germany 1697 computer-aided telephone interviews were undertaken in flood affected private households. Besides the damage to buildings and contents a variety of factors that might influence flood damage were queried. In this paper it is analysed how variables describing flood impact, precaution and preparedness as well as characteristics of the affected buildings and households vary between the lower and upper damage quartiles of all affected households. The analysis is supplemented by principal component analyses. The investigation reveals that flood impact variables, particularly water level, flood duration and contamination are the most influencing factors for building as well as for content damage. This group of variables is followed by items quantifying the size and the value of the affected building/flat. In comparison to these factors temporal and permanent resistance influences damage only to a small fraction, although in individual cases precaution can significantly reduce flood damage.

Keywords: flood impact, principal component analysis, damage, loss modelling

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1 INTRODUCTION

Risk-oriented methods and risk analyses are gaining more and more attention in the fields of flood design and flood risk prevention since they allow us to evaluate the cost-effectiveness of projects and thus to optimise investments (e.g. Resendiz-Carrillo and Lave, 1990; USACE, 1996; Olsen et al., 1998; Al-Futaisi and Stedinger, 1999; Ganoulis, 2003). Moreover, risk analyses quantify the (residual) risks and thus enable communities and people to prepare for disasters (e.g. Takeuchi, 2001; Merz and Thieken, 2004). For example, risk maps such as the ICPR Rhine-Atlas (ICPR, 2001) improve public flood risk awareness. In this context, flood risk encompasses two aspects, the flood hazard (i.e. extreme events and associated probabilities) and the consequences of flooding (Mileti, 1999). Thus, besides meteorological, hydrological and hydraulic investigations such analyses require the estimation of flood impacts, which is normally restricted to detrimental effects, i.e. flood losses.

Flood loss estimation is also an important issue for insurance and reinsurance companies. To guarantee solvency the probable maximum loss (PML) of their portfolios has to be estimated. For risk-based design and insurance purposes reliable flood loss models have to be developed. A thorough analysis of flood damage data is a basis for model development.

Flood losses can be classified into direct and indirect losses. Direct losses are those which occur due to the physical contact of the flood water with humans, property or any other objects. Indirect losses are induced by a flood, but occur – in space or time - outside the actual event. Examples for indirect losses are disruption of traffic, trade and public services. Usually, both types of losses are further classified into tangible and intangible damage, depending on whether or not they can be assessed in monetary values (Smith and Ward, 1998).

The largest part of the literature on flood loss estimation concerns direct tangible damage (Merz and Thieken, 2004). Although it is acknowledged that direct intangible damage or indirect damage play an important or even dominating role in evaluating flood impacts (FEMA, 1998; Penning-Rowsell and Green, 2000) these damage categories are not treated here. The present study is limited to direct monetary flood damage to buildings and contents of private households.

A central idea in flood loss estimation is the concept of damage functions or loss functions. Most functions have in common that the direct monetary damage is related to the type or use of the building and the inundation depth (e.g. Smith, 1981; Krzysztofowicz and Davis, 1983; Wind et al., 1999; NRC, 2000; Green 2003). This concept is supported by the observation “that houses of one type had similar depth-damage curves regardless of actual value” (Grigg and Helweg, 1975). Depth-damage functions are seen as the essential building blocks upon which flood damage assessments are based and they are internationally accepted as the standard approach to assessing urban flood damage (Smith, 1994).

Usually, building-specific damage functions are developed by collecting damage data in the aftermath of a flood. Another data source are “what-if analyses” by which the damage which is expected in case of a certain flood situation is estimated, e.g. “Which damage would you expect if the water depth was 2 m above the building floor?” On the basis of such actual and synthetic data, generalised relationships between damage and inundation depth have been derived for different regions. Green (2003) provides stage-damage curves for different building types and uses in various countries, e.g. UK, USA, Japan. Probably the most comprehensive approach has been the "Blue Manual" which contains more than 150 stage-damage curves for both residential and commercial property in the UK (Penning-Rowsell and Chatterton, 1977). These damage functions also consider two groups of flood duration (less than 12 hours and more than 12 hours).

While the outcome of most of the loss functions is the absolute monetary loss to a building, some approaches provide relative depth-damage functions, i.e. the damage is given in percentage of the building value (e.g. Dutta et al., 2003), or as index values, e.g. damage may be expressed as an equivalent to the number of median-sized family houses totally destroyed (Blong, 2003). If these functions are used to estimate the loss due to a given flood scenario property values have to be predetermined.

Recent studies have shown that stage-damage functions may have a large uncertainty since water depth and building use only explain a part of the data variance (Merz et al., 2004). Moreover, assessments of flood damage and flood characteristics (water level, velocity, etc.) at affected properties are in most instances based on subjective perceptions of building surveyors and may therefore be prone to variation (Soetanto and Proverbs, 2004). Thus, definite benchmarks of flood damage assessment should be developed which will also allow an assessment of possible repair strategies (Proverbs and Soetanto, 2004).

Flood damage is influenced by many more factors among which are flow velocity, flood duration, contamination, sediment concentration, lead time and information content of flood warning, and the quality of external response in a flood situation (Smith, 1994; Penning-Rowsell et al., 1994; USACE, 1996; Nicholas et al., 2001; Kelman and Spence, 2004). Except for conceptual models, these aspects are, however, scarcely included in flood loss models. Following the concept that the damage of a building is dependent upon the load on the structure on the one hand and its resistance on the other hand the influencing factors can be classified as proposed in Fig. 1.

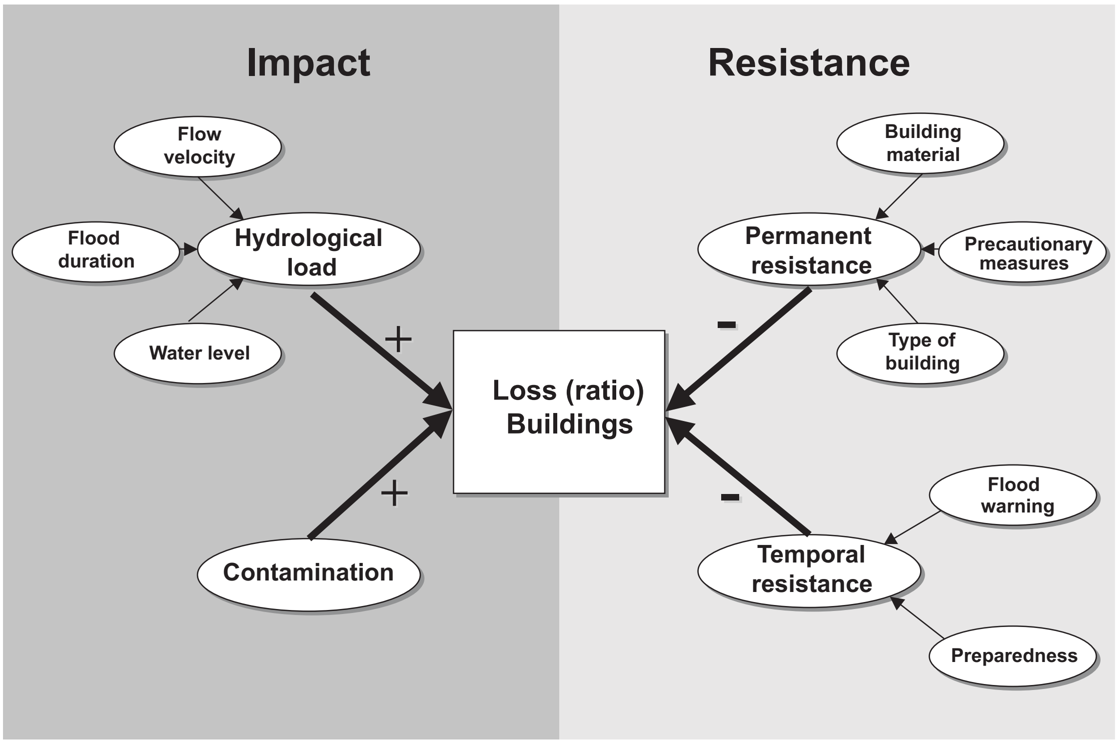

Fig. 1: Factors that influence the flood loss (ratio) of buildings.

Typical flood loss patterns can be described as follows (Kelman and Spence, 2004): rising floodwater or groundwater soaks through building walls, floors and furniture. The damage related to hydrostatic flood action with lateral pressure and capillary rise can be greatly enhanced by sediment deposits or (oil) contamination. A (partial) collapse of the building might occur due to a scour of (shallow) foundations or a collapse of supporting walls. This loss profile of mostly hydrodynamic flood action is greatly influenced by flow velocity (Kelman and Spence, 2004). Finally, a building can be buoyed if the force of rising floodwater or groundwater exceeds the counterweight of the building. Hence, buoyancy of a building can be prevented by flooding of the basement on purpose.

Although a few studies give some quantitative hints about the influence of some of the factors shown in Fig. 1 on flood loss (McBean et al., 1988; Smith, 1994; Wind et al., 1999; Penning-Rowsell and Green, 2000; ICPR, 2002; Kreibich et al., 2005a) there is no comprehensive approach for including these factors in a loss estimation model. Wind et al. (1999) state that "flood damage modelling is a field which has not received much attention and the theoretical foundations of damage models should be further improved". More research on the methodology of flood loss estimation and more flood loss data were already demanded by Ramirez et al. (1988). Kelman and Spence (2004) still confirm that "more work is needed in order to fully understand how flood damage arises and, hence, how flood damage may be prevented." Therefore, the goal of this paper is to analyse flood damage in private households and several influencing factors on the basis of damage data that were gathered in the aftermath of a severe flood event in Germany in 2002. The analysis shall lead to some conclusions which of the various factors shown in Fig. 1 should be included in flood loss modelling.

2 INVESTIGATION AREA, DATA AND METHODS

In August 2002 a severe flood event hit Germany, Austria, the Czech Republic and Slovakia along the rivers Elbe, Danube and some of their tributaries. Return periods even exceeded 500 years at some tributaries of the Elbe and the return period along the Elbe varied between 150 years at Dresden (Upper Elbe) and 25 years at the Lower Elbe near Hamburg (IKSE, 2004; Engel, 2004). In Germany, 21 people were killed and substantial parts of the infrastructure were destroyed in some of the affected regions. Altogether, damage of about 11.6 billion euro was caused. The most affected German federal state was Saxony, where the total flood damage amounted to 8.7 billion euro, followed by Saxony-Anhalt (1187 million euro) and Bavaria (198 million euro) (data from IKSE, 2004; SSK, 2004; pers. comm. Bavarian Ministry of Finance).

2.1 Data: Surveying flood affected private households

To investigate damage influencing factors a survey among flood affected private households was undertaken in Germany in the aftermath of the 2002 flood. The investigation area covered regions in the Elbe catchment (Saxony, Saxony-Anhalt) and in the Danube catchment (Bavaria) which had been affected by different flood types (cf. Fig. 2) and which differ in socio-economic structure, i.e. in income, purchasing power and building structure, and in flood experience. In the Danube catchment a severe flood event occurred in 1999, while in the Elbe catchment the last severe floods occurred in the 1950ies. Thus, a broad variation of hydrological and socio-economical conditions was likely to be included in the survey.

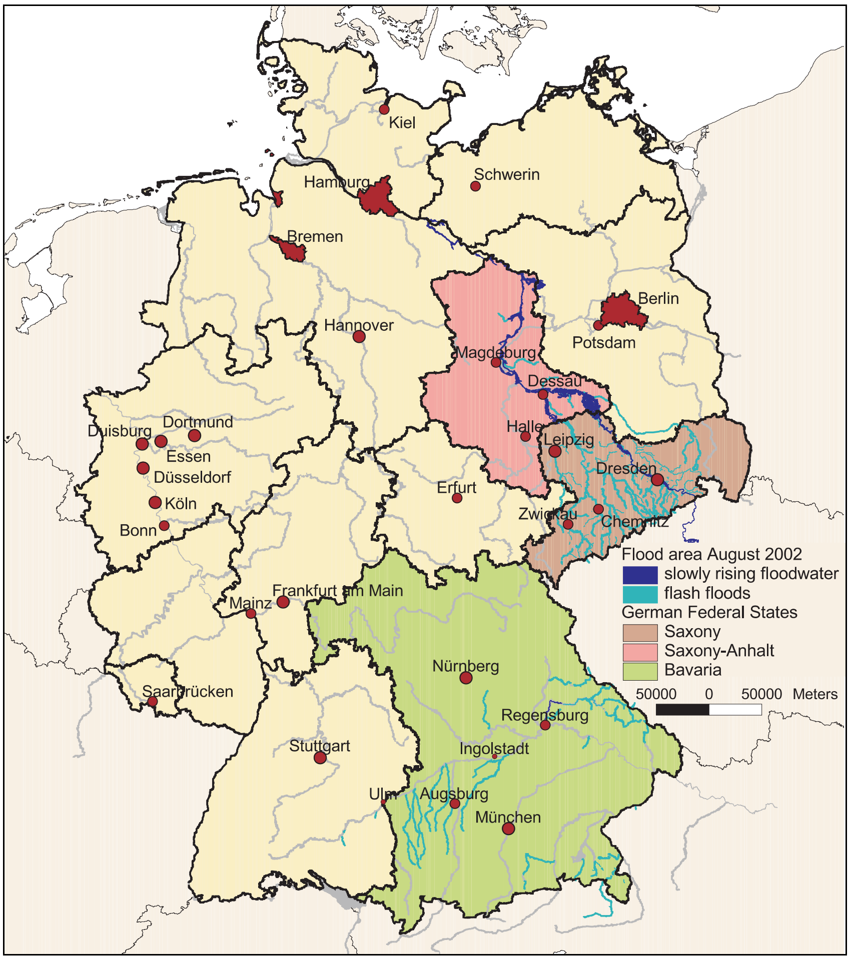

Fig. 2: Inundated area and corresponding flood type during the August 2002 flood in Germany and the three most affected federal states (Data sources: DLM1000, VG250, Hochwasserlinien des Elbe-Hochwassers © BKG, Frankfurt a.M., 2004; Überschwemmungsgebiet der Mulde in Sachsen-Anhalt: UFZ Leipzig, 2003; Überschwemmte Flächen Hochwasser in Sachsen August 2002: Sächsisches Landesamt für Umwelt und Geologie, Staatliche Umweltfachämter Chemnitz, Leipzig, Plauen und Radebeul, Landestalsperrenverwaltung Sachsen, Stadtverwaltungen Landeshauptstadt Dresden/Umweltamt, Chemnitz/Umweltamt, Zwickau/Umweltamt und Olbernhau; Informationssystem Wasserwirtschaft der bayerischen Wasserwirtschaftsverwaltung 2004 (www.bayern.de/lfw)).

On the basis of information from the affected communities and districts, lists of inundated streets in the study areas were comprised and a building specific random sample of households was generated. The interviewees were questioned about the flood damage at their buildings and household contents as well as about factors which might have influenced the extent of damage. In total, 1697 computer-aided telephone interviews were undertaken by the SOKO-Institute, Bielefeld, Germany, in April and May 2003 with the help of the VOXCO software package. Altogether, the questionnaire contained about 180 questions addressing the following topics: flood impact (e.g. water level), additional hazardous impacts (e.g. oil contamination), flood warning, emergency measures, evacuation, cleaning-up, characteristics of and damage to household contents and buildings, recovery of the affected household, precautionary measures, flood experience and awareness as well as socio-economic variables. A detailed description of the survey can be found in the work of Kreibich et al. (2005a) and Thieken et al. (2007). Since each topic was addressed by a number of questions and often multiple answers were possible, data aggregation was needed (see section 2.3). Beforehand, cross-checks and validity checks of the answers were undertaken to improve data quality, especially with regard to data about the affected and total area, affected stories, damage estimates and estimates of the total property value. It turned out that e.g. the reliability of the answers concerning the property value was very low since the stated damage regularly topped the denoted value. Since most of the affected people claimed their losses either from governmental funds or from their insurers the damage estimates are more reliable. This was also confirmed by a comparison with damage data from the Saxon Bank (Sächsische Aufbaubank) which was responsible for the governmental disaster assistance in Saxony.

2.2 Data processing: determining values of buildings and contents

The raw data were supplemented by estimates of values of buildings and household contents and of loss ratios, i.e. the relation between the building/content damage and the corresponding value.

The absolute values of buildings were estimated according to the VdS guideline 772 1988-10 (Dietz, 1999) which is commonly used in the insurance sector. It provides mean building values in "Mark 1914" per m² living area for different building types. The building type and the living area of a building were determined with the help of the answers concerning the total floor space of the building, the number of stories, the basement area and the roof-type. The mean building values were up- or degraded depending on the quality and equipment of the building, e.g. the heating system (Dietz, 1999). The resulting insurance sum in "Mark 1914" can be transferred to a replacement value of any given year by the price index for buildings published by the German Federal Statistical Agency. For the reference year 2002, the mean building value in the survey data amounted to about 319,000 € for one-family houses and 607,000 € for multifamily buildings. The estimated values are in the same order of magnitude than mean insurance sums provided by the Association of German Insurers (GDV).

The value of household contents was estimated by the following regression model:

$val = -14.412 + 341.060 * larea + 3.176 * pp\_rt$

with:

val: value of household contents [Euro],

larea: living area of the interviewed household [m²] and

pp_rt: purchasing power relevant to retail trade in the zip code area of the interviewed household [Euro].

The parameters of the regression model were derived by a regression analysis of data about the average household content insurance sum in the zip code areas of the surveyed federal states as well as the average living area per household and the purchasing power relevant to retail trade in these zip code areas (data source: S-mikromarkt/Acxiom 2003). The regression yielded a coefficient of determination of $R^2 = 0.757$. The mean value of household contents of the surveyed households amounted to about 58,000 €, with a minimum value of 27,965 € and a maximum value of 500,000 €. The mean value is in the same order of magnitude than the mean insurance sum provided by the GDV.

2.3 Data processing: derivation of indicators

To better handle the large data set, answers concerning one particular topic were aggregated into one indicator variable. This was done for flow velocity, contamination, flood warning, emergency measures, precautionary measures, flood experience and socio-economic variables.

Flow velocity While the water depth at or inside the affected building or the duration of the inundation can be reliably given by the interviewees, this is much more difficult for flow velocity since most people do not have enough experience to estimate velocities. Therefore, flow was approximated by two descriptive scales. On the first scale water flow had to be assessed from 1 (= calm and low flow) to 6 (= turbulent and rapid flow), on the second the danger of the inundation for an adult person had to be estimated. The latter scale was built upon the work of Bureau of Reclamation (1988), in which the danger for an adult person in dependence of water level and flow velocity is given and divided into three classes. The scale used in the interviews corresponded to these classes and was supplemented by a fourth class for the case that the water level was too high for an adult person to stand in. For water levels from 0 m to 1.5 m above surface ground the interviewees' assessment of the danger was used to roughly estimate a range of flow velocity according to Bureau of Reclamation (1988).

The interviewees were also asked about transported and deposited material, e.g. sand, stones, boulders. Together with the corresponding water level this information was used to derive a flow velocity on the basis of the Shield's diagram modified by USACE (1996). Velocities could be appraised to 974 cases and ranged from 0.9 m/s to 6.1 m/s. The data were then classified into moderate (< 1.5 m/s), high (1.5 to 4.5 m/s) and very high (> 4.5 m/s) velocities (Nicklisch, 2004).

The velocity classes as well as the water level and the two qualitative velocity assessments were used in a discriminant analysis in order to assign velocity classes to cases where the information on transported material was missing. By means of the resulting discriminant functions velocity classes could be assigned to a total of 1460 cases. Since only 57.4% of the primary cases were correctly classified, the classification was revised on the basis of rules that also considered the flood region and flood type, the damage to the building fabric (assessed on a scale from 1 'no damage to the building fabric" to 6 "severe damage to the building fabric, danger of building collapse") and the way the water intruded the building (from the bottom through sinks, lavatories, washbasins, etc. or from outside through windows, doors, holes etc.). In this step, a fourth velocity class was introduced for cases where flood damage was due to (slowly) rising groundwater, backwater or stagnant flow. For example, this class was assigned when the water level was below surface, i.e. water was only in the basement, the interviewee stated that the water intruded from the bottom and the flow velocity was assessed to be very low on both scales. Altogether, the interviews were classified into: mainly ground-/backwater induced (133 cases), moderate (856 cases), high (635 cases) and very high velocities (43 cases). Owing to missing data no flow velocity class could be appraised to 30 cases.

Contamination The multiple answers concerning the contamination of the flood water by sewage, chemicals or oil/petrol were aggregated to an ordinal scale. Cases with no contamination obtained zero points; cases that were only contaminated by sewage received one point. Cases with (additional) contamination by chemicals obtained two points, cases with (additional) contamination by oil or petrol got three points.

Tab. 1: Assessment of flood warning sources and information.

Source of flood warning	Assessment points	Information content of the flood warning	Assessment points
flood warning by local authorities	4	information about residential areas at risk	2
Warned by own observations	2	advice for damage reduction	4
warning by nationwide news	3	information about peak water level	2
warning by neighbors, friends etc.	1	information about time to peak water level	2
warning and evacuation at the same time	0	information about evacuation	1
other warnings	1	information about levee breaches, expected rainfall	2
no warning	0	information about inundated streets	1

Tab. 2: Damage reduction by emergency measures resulting from a comparison of cases where the measure was not undertaken (A) with cases where the measure was undertaken very effectively (B) and weighting of different measures for an overall emergency indicator (Legend: n: total number of cases; w: weight for indicator; indication of difference in damage: *No damage reduction*; **Damage reduction significant on 0.05 level**).

Emergency measure	n (A)	n (B)	Difference in absolute content damage [€]	Difference in content loss ratio [-]	Difference in absolute building damage [€]	Difference in building loss ratio [-]	W
Safeguard documents and valuables	775	731	*5731*	*0.10*	*21099*	*0.06*	0
Drive vehicles to a flood safe place	749	802	*3856*	*0.06*	*15669*	*0.03*	0
Switch off gas / electricity	884	657	*2928*	*0.06*	*7663*	*0.06*	0
Disconnect household appliances	1105	356	-19	*0.00*	-792	*0.01*	1
Put moveable contents and furniture upstairs	725	400	-2149	-0.05	**-20572**	**-0.04**	2
Protect oil tanks	1502	119	-1452	-0.05	**-15015**	**-0.03**	2
Protect the building against inflowing water (by sandbags etc.)	838	121	-1522	**-0.08**	**-25015**	**-0.07**	5
Install a water pump	1622	24	**-12671**	**-0.23**	**-36792**	**-0.10**	5
Seal drainage / prevent backwater	1676	8	-3442	-0.08	-13364	-0.04	1
Redirect water flow	1681	5	-12054	-0.22	**-40357**	**-0.10**	2
Temporary local flood protection (e.g. by a dam)	1683	3	*1168*	-0.02	-33065	-0.10	1

Flood warning Answers concerning the sources of flood warnings (check list with different sources: local authorities, national news, own observation, friends, relatives or neighbours; open and multiple answers possible) and the information content of the warnings (check list with different pieces of information: residential areas at risk, peak water level, time to peak water level, advices for damage reduction or self protection; open and multiple answers possible) were assessed as shown in Tab. 1. The indicator value for the warning source is determined by the source that was judged as the most reliable and thus received the most assessment points (Tab. 1). The indicator for the warning information assembles from the assessment points for the single pieces of information.

Emergency measures The interviewed people were asked whether or not they had undertaken emergency measures such as putting movables and furniture upstairs, protecting the building against inflowing water etc.. The check list contained eight different measures and could be supplemented by open answers; multiple answers were possible. The interviewees were then asked to evaluate the efficiency of each measure on a rank scale from 1 (= measure was very effective) to 6 (= measure was very ineffective). In order to aggregate all answers each performed measure received seven points whereof the rank for efficiency was subtracted so that a very effectively performed measure gained six points, while a very badly performed measure only got one point.

For an overall indicator for emergency measures, the individual measures were weighted in relation to their damage reducing effect. The weights in Tab. 2 were derived by comparing the damage in the data subset where a certain measure was not performed with the subset where the measure was performed very effectively. Measures that did not show a damage reducing effect were neglected (weight = 0). Measures that did not reduce damage significantly gained one point. Measures that led to a significant reduction in either building or content damage were assessed by two points whereas measures that reduced both building and content damage significantly received five points. The significance of damage reduction also depends on the number of cases. Thus, measures with a small sample size, e.g. the measure "redirect water flow" received a comparatively low weight (Tab. 2).

Precautionary measures The interviewees were asked about the long-term precautionary measures that they had undertaken before August 2002. The check list contained nine different measures (two informational measures, i.e. gathering information about precautionary measures and joining neighbourhood flood networks, flood insurance and six different building precautionary measures, e.g. flood adapted building use, sealing of the building) and could be supplemented by open answers; multiple answers were possible. The damage reducing effect of the individual measures is presented in the work of Kreibich et al. (2005a). For this investigation an aggregated indicator for long-term precaution is used. Since the informational measures and flood insurance did not generate a significant reduction in flood damage, only building precautionary measures were considered. The indicator simply consists of the number of performed measures.

Flood experience Flood experience was addressed by three questions: the number of experienced floods, the time period since the last experienced flood and the question whether or not previous flood losses of more than 1000 Euro had occurred. The first two variables were each aggregated into six classes whereby the class number increased for a recurrent (i.e. no flood experience = 0, one previous flood = 1 … more than four previous floods = 5) and more recently achieved flood experience (no flood experience = 0, last experienced flood event is at least 25 years ago = 1 … last experienced flood event is at the most two years ago = 5). The indicator was composed by adding the class numbers of the first two variables and multiplying it with a factor of 0.7 if the third variable was false, i.e. if no monetary damage had been experienced. Thus, the indicator ranges from 0 to 10.

Socio-economic status (SES) Socio-economic status was determined and classified according to the work of Plapp (2003) considering school graduation, ownership structure and living area per person as well as after a more traditional approach examining education (including graduation, professional training and university degrees), job position and monthly net income of the household (Schnell et al., 1999). Each input item was transferred to a rank scale with four to six classes. Both indicators were composed by the sum of ranks of their input items and were finally classified into four or five classes, respectively.

2.4 Methods of data analysis

To investigate which factors determine flood damage four damage items, i.e. absolute damage to contents and buildings as well as the corresponding loss ratios were investigated. First, each damage item was divided into its quartiles. The differences of the other variables (flood characteristics, flood warning, precaution etc.) were then analysed in the upper and the lower quartile (0.75-quantile and 0.25-quantile, respectively) of each damage item. Significance of the differences between the average parameters in both quartiles was judged by the Mann-Whitney-U-Test, with significance levels of $p < 0.01$ and $p < 0.05$. The analysis was supplemented by principal component analyses (PCA) with varimax rotation in order to investigate the correlation structure of the damage influencing variables. Statistical analysis was undertaken by means of the software package SPSS for Windows, Version 11.5.1.

3 RESULTS AND DISCUSSION

Of the 1697 surveyed households, 1489 households reported damage to their household contents, 1340 to their building. From these, 1273 households specified a monetary damage to the contents, 1079 a monetary building damage. The mean damage amounted to 16,335 € and 42,093 €, respectively (Tab. 3).

The four damage variables (absolute content damage, absolute building damage as well as the corresponding loss ratios) are interrelated, i.e. all damage items are always significantly higher in the 0.75-quantile of all other damage variables than in the 0.25-quantiles. Thus, households with a content damage in the upper quartile also had a higher damage to the building and vice versa.

The number of affected stories and the share of people who had to leave their residence during the flood were also higher in the 0.75-quantiles of all four damage variables (data not shown). Further analyses were done for a range of parameters shown in Fig. 1.

3.1 Flood impact: Effects of hydrological load and contamination on flood losses

The flood impact was distinguished into the impact of the flood water itself (hydrological load) and additional contamination of the water (cf. Fig. 1). Hydrological load is represented by water depth, flood duration and the flow velocity indicator. All impact variables are significantly higher in the 0.75-quantiles than in the 0.25-quantiles of all four damage variables (Tab. 4), i.e. the high losses/loss ratios in the upper quartiles were caused by higher water levels, longer flood durations, faster flow velocities and the existence of contamination.

Fig. 3 shows exemplarily how the loss ratio of buildings is related to the four impact variables. The loss ratio is continuously rising with increasing water depth up to the water depth class “151 to 250 cm”. The median loss ratio in higher water level classes almost remains on a constant level that exceeds the 0.75-quantile of the loss ratios of the total data set (Fig. 3A).

The median loss ratio rises significantly with increasing flood duration up to the duration class “> 7 to 14 d” (Fig. 3B). Longer flood durations do not cause considerable higher loss ratios.

There is a large difference in loss ratios of buildings affected by groundwater rise or stagnant flow on the one hand and very high flow velocities on the other hand (Fig. 3C). However, the number of valid cases is comparatively low. Buildings affected by moderate or high flow velocities both show intermediate loss ratios, but they cannot be distinguished from each other. Thus, the influence of flow velocity on loss ratios is not as clear as the influence of water level and flood duration.

Tab. 3: Statistics of damage variables during the August 2002 flood in Germany.

	n	mean	0.25-quantile	median	0.75-quantile
Absolute damage to household contents	1273	16335 €	2500 €	8000 €	25000 €
Absolute damage to buildings	1079	42093 €	6000 €	24000 €	60000 €
Loss ratio of household contents	1240	29.6%	5.2%	15.8%	45.6%
Loss ratio of buildings	947	12.3%	1.9%	6.4%	17.8%

Tab. 4: Significance of differences of damage influencing variables with regard to hydrological load and contamination of flood water in the lower (0.25-quantile) and upper quartile (0.75-quantile) of different damage items (Signature: ++: Variable values are higher in 0.75-quantile of the damage item; level of significance ≤ 0.01; +: Variable values are higher in 0.75-quantile of the damage item; level of significance ≤ 0.05; o: Variable values do not differ significantly between the upper and the lower quartile of the damage item; -: Variable values are lower in 0.75-quantile of the damage item; level of significance ≤ 0.05; --: Variable values are lower in 0.75-quantile of the damage item; level of significance ≤ 0.01).

Items on flood impact	absolute damage to contents	loss ratio of contents	absolute damage to buildings	loss ratio of buildings
water level above top ground surface [cm]	++	++	++	++
flood duration (hours)	++	++	++	++
indicator for flow velocity (see section 2.3) [-]	+	++	++	++
contamination of the flood water (see section 2.3) [-]	++	++	++	++

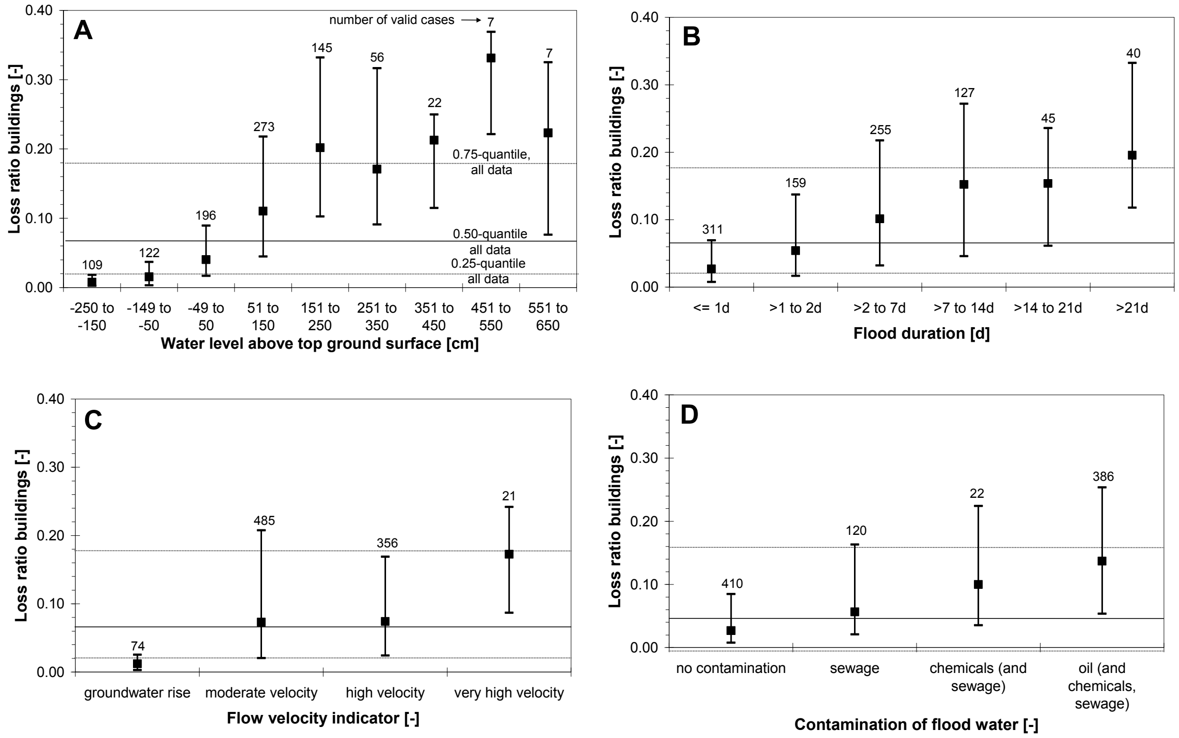

Fig. 3: 0.25-, 0.50-, and 0.75-quantiles of loss ratios of buildings in relation to water level (A), flood duration (B), flow velocity indicator (C), and contamination (D). The horizontal lines represent the 0.25-, 0.50-, and 0.75-quantiles of the building loss ratios of the total data set as shown in Tab. 3. The composition of the indicators is outlined in section 2.3.

Finally, contamination, particularly by oil, causes an increase in the loss ratio of buildings (Fig. 3D). The median of the class with oil contamination (and additional contamination by sewage and/or chemicals, if applicable) is about five times higher than the median of the class with no contamination. The mean values of both classes differ by a factor of 2.6 (data not shown).

The analysis confirms that flood characteristics enormously influence the extent of flood losses which is in consistence with current flood loss modelling, where water level is the key parameter (Smith, 1994). While flood duration and flow velocity are considered in a few models (cf. Kelman and Spence, 2004), the damaging effect of contamination has not expanded into flood loss models except for the conceptual model presented by Nicholas et al. (2004). This might be due to the difficulty of contamination prognosis. While water levels can be easily provided by hydraulic modelling, the provision of flood durations and flow velocities demands more sophisticated hydraulic models. For the prognosis of contamination even more data, assumptions and modelling efforts are needed.

3.2 Resistance: Effects of temporal and permanent resistance

Flood damage can be prevented or limited by long-term precautionary measures as well as by emergency measures which are undertaken just before or during a flood (cf. Section 2.3). For the performance of the latter flood warning is an important premise. Furthermore, flood experience influences private precautionary behaviour (Kreibich et al., 2005a; Thieken et al., 2007). The influence of these variables on the flood damage items in our survey is shown in Tab. 5. Fig. 4 illustrates how loss ratios of household contents and buildings are related to selected factors.

Tab. 5: Significance of differences of potentially damage reducing factors in the lower (0.25-quantile) and upper (0.75-quantile) quartile of different damage items. (Signature: see Tab. 4).

Items on …	absolute damage to contents	loss ratio of contents	absolute damage to buildings	loss ratio of buildings
… flood warning and emergency measures				
indicator of flood warning source (see Tab. 1)	++	++	++	++
warning time [hours]	++	++	++	++
indicator of flood warning information (see Tab. 1)	++	++	++	++
knowledge of the interviewed persons how to protect themselves and their household against the flood water on a scale from 1 (I knew what to do) to 6 (I didn't know what to do)	++	++	++	++
lead time period elapsed without using it for emergency measures	++	++	++	++
indicator of emergency measures (see Tab. 2)	o	-	--	--
… private precautionary measures				
indicator of precautionary measures (retrofitting) (see section 2.3)	--	--	--	--
efficiency of private precautionary measures assessed by the interviewed person on a scale from 1 (flood damage can be significantly reduced by private precaution) to 6 (flood damage cannot be reduced by private precaution at all)	++	++	++	++
… flood experience				
indicator of flood experience (see section 2.3)	o	o	--	--
knowledge about the flood hazard of their household	+	+	o	o

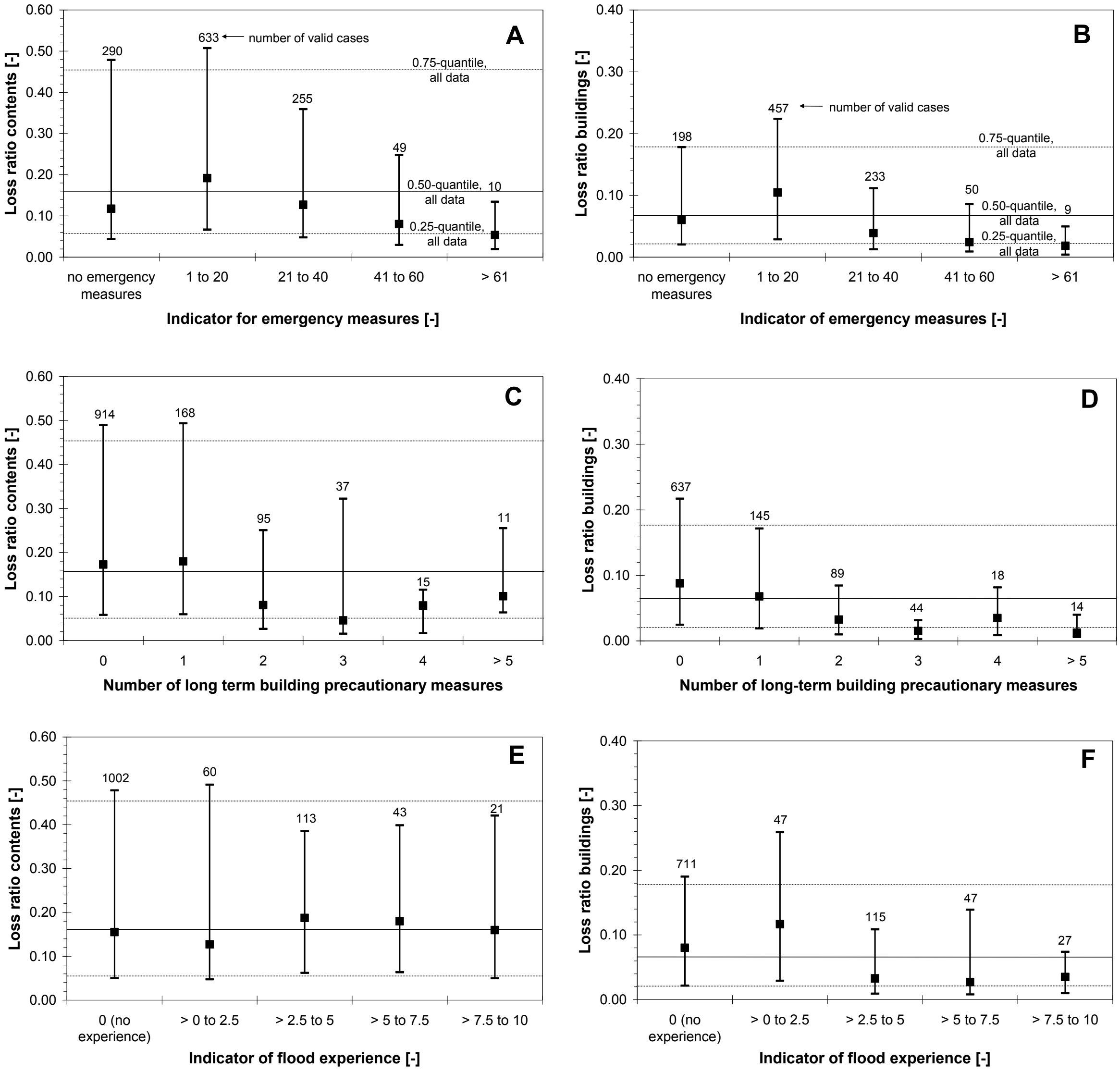

Fig. 4: 0.25-, 0.50-, and 0.75-quantiles of loss ratios of contents and buildings in relation to the indicators for emergency measures (A, B), long-term building precaution (C, D), and flood experience (E, F). The horizontal lines represent the 0.25-, 0.50-, and 0.75-quantiles of the loss ratios of the total data set as shown in Tab. 3. The composition of the indicators is outlined in section 2.3.

Surprisingly, flood warning was better in the 0.75-quantiles of all damage variables, i.e. there were more official warnings with better information and longer lead times for households with the highest losses and loss ratios (Tab. 5). On the other hand, the share of people who did not know how to protect themselves and their household against the flood water was also higher in all 0.75-quantiles and so was the time period that had elapsed after the warning before emergency measures were undertaken (Tab. 5). This might explain why flood warning did not reveal damage reduction in this case study. One has to conclude that flood warning alone cannot prevent flood damage – particularly if the flood event is very extreme like the August 2002 flood. For the purpose of damage reduction flood warning has to be followed by effective emergency measures. Tab. 5 reveals that emergency measures, which are suitable to reduce flood damage (see Tab. 2), show significant influence on the building damage. A less significant influence is found for the loss ratio of household contents. Fig. 4A and 4B illustrate that cases with no or little emergency measures show a higher median loss ratio than cases where many and/or very effective measures were undertaken.

One would have expected that losses to household contents could be reduced by emergency measures to a greater extent than losses to buildings. However, one has to consider that damage to fixed contents, e.g. windows, doors, wallpaper, floor covering and electrical equipment, are usually assigned to the building damage so that the most efficient emergency measures (protecting the building against inflowing water and installing a water pump, cf. Tab. 2) might prevent a huge amount of building damage, as well. If the mean values of all cases without emergency measures and with effective emergency measures (indicator values from 41 to 60) are compared, then the mean loss ratio of buildings with emergency measures amounts to 50% of the loss ratio of cases without emergency measures. With regard to the loss ratio of contents this value is 62%. In the investigation of Penning-Rowsell and Green (2000) damage in the residential sector could be reduced by flood warning and emergency measures to 87%, in the work of Smith (1981) to 52.4% of the potential damage.

To sum up, the impact of flood warning on flood damage depends not only on the reliability of the flood warning process, but also on the proportion of residents available to respond to a warning, the proportion of residents able to respond to a warning and the proportion of residents who respond effectively (Penning-Rowsell and Green, 2000). Thus, the benefits of flood warning with regard to damage reduction only begin to be realised when the total forecasting, warning and response system is operating effectively, and usually this is not the case (Parker, 1998).

Precautionary measures, which are installed permanently and which were usually accomplished (long) before the flood event, show a significant difference in the 0.25- and the 0.75-quantiles of all damage variables, i.e. the extent of flood-adapted building retrofitting is significantly higher in 0.25-quantiles, where also a higher share of people has been thinking that private precautionary measures can effectively reduce flood damage (Tab. 5). Fig. 4C and 4D illustrate that cases with two or more precautionary measures were damaged to a lesser extent than cases with no or only one precautionary measure. However, the number of cases with extensive precaution is comparatively small. The damage reduction by precautionary measures is discussed in detail in the work of Kreibich et al. (2005a).

The indicator for flood experience differs significantly when comparing the 0.25- and 0.75-quantiles for building damage (absolute and loss ratio): More flood experience exists among people in the 0.25-quantiles (Tab. 5). However, there is no distinction between the flood experience in the upper and lower quartiles of content damage (absolute and loss ratio). This is further illustrated by Fig. 4E and 4F: While the median loss ratios of contents do not differ much with a change in flood experience, the median loss ratios of buildings as well as the interquartile ranges are considerably lower when the indicator for flood experience exceeds 2.5. An indicator value of less than 2.5 was given if previous floods had been experienced more than 25 years ago and if no flood damage had appeared. The long mitigation effect of flood experience with regard to building damage can be explained by the fact that flood experience motivates people to invest in building retrofitting (see Kreibich et al., 2005a; Grothmann and Reusswig, 2006) which leads to a long-term damage mitigation. For a reduction of losses to contents flood experience has to be achieved more recently and frequently (cf. Smith, 1994).

The pure knowledge about flood hazard does not lead to the same effect. It has no significant influence on the building damage items (Tab. 5). However, more people in the 0.75-quantiles of the content damage (absolute and relative), i.e. with high damage to household contents, knew more frequently that they have been living in a flood prone area (Tab. 5). This underlines that knowledge about flood hazard has to be combined with knowledge and implementation of preparative and precautionary measures in order to limit flood losses.

3.3 Characteristics of the affected buildings and households

Besides flood impact, temporary and permanent resistance, other characteristics of affected buildings and household contents as well as socio-economic items of the affected households might also influence the extent of flood damage. This topic is investigated by a number of factors listed in Tab. 6. Fig. 5 and 6 illustrate in more detail how the loss ratios of household contents and buildings are related to selected variables.

The building type – with regard to building size, not to building material which would be part of permanent resistance - was evaluated as follows: One-family houses were assessed with one point, semidetached houses with two points, row or terraced house with three and multifamily houses with four. Tab. 6 reveals that the scores are significantly higher in the upper quartile of absolute building losses, whereas they are significantly lower for the other damage items. Roughly, this means that multifamily houses, of course, received a very high absolute building damage, but their loss ratio, in which damage is related to the building value, is smaller in comparison to one-family houses. Moreover, the absolute content damage and the loss ratio of contents are smaller in households that live in a multifamily house.

Tab. 6: Significance of differences in the characteristics of the affected households and buildings in the lower (0.25-quantile) and upper (0.75-quantile) quartile of different damage items (Signature: see Tab. 4).

Items on ...	absolute damage to contents	loss ratio of contents	absolute damage to buildings	loss ratio of buildings
… characteristics of the residence/building				
building type (1: one-family house ... 4: multifamily house)	--	-	++	-
total number of flats in the building	--	--	++	--
total living area of the household	++	++		
total floor space of the building			++	--
quality of household contents before the flood assessed on a scale from 1 (very good, luxurious) to 6 (very bad)	--	--		
quality of building before the flood assessed on a scale from 1 (very good, luxurious) to 6 (very bad)			--	--
estimated value of household contents (see section 2.2)	++	+		
estimated building value (see section 2.2)			+	--
... socio-economy of the affected household				
age of the interviewed person	o	+	o	++
number of children (younger than 14 years)	o	-	o	--
number of elderly persons (older than 65 years)	o	o	o	o
household size	++	o	-	-
ownership structure (low value = tenants, high value = flat/building owner)	++	++	--	++
monthly net income of the household	++	o	-	++
socio-economic status according to Plapp (2003)	++	++	o	o
socio-economic status according to Schnell et al. (1999)	+	o	o	o

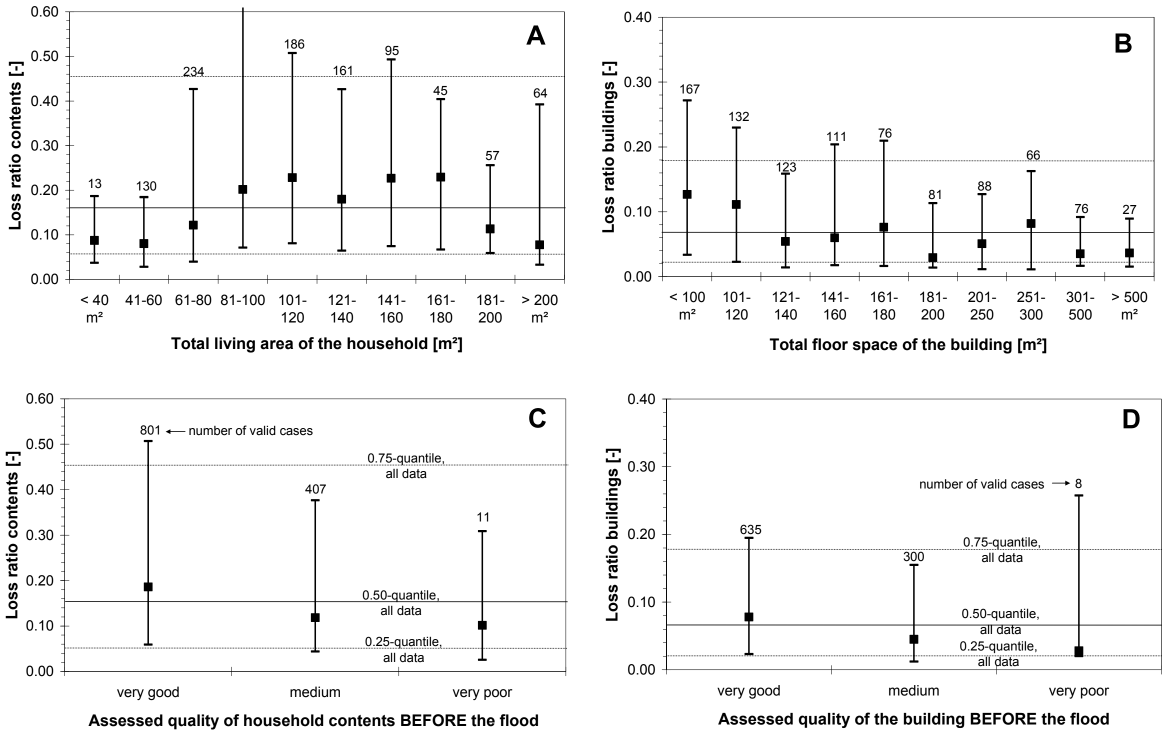

Fig. 5: 0.25-, 0.50-, and 0.75-quantiles of loss ratios of contents and buildings in relation to the total living area of the household (A)*, the total floor space of the building (B), the assessed quality of households contents (C) and building (D) before the flood in August 2002. The horizontal lines represent the 0.25-, 0.50-, and 0.75-quantiles of the loss ratios of the total data set as shown in Tab. 3.

*The 0.75-quantile of the loss ratios in interval 81-100 m² amounts to 0.64.

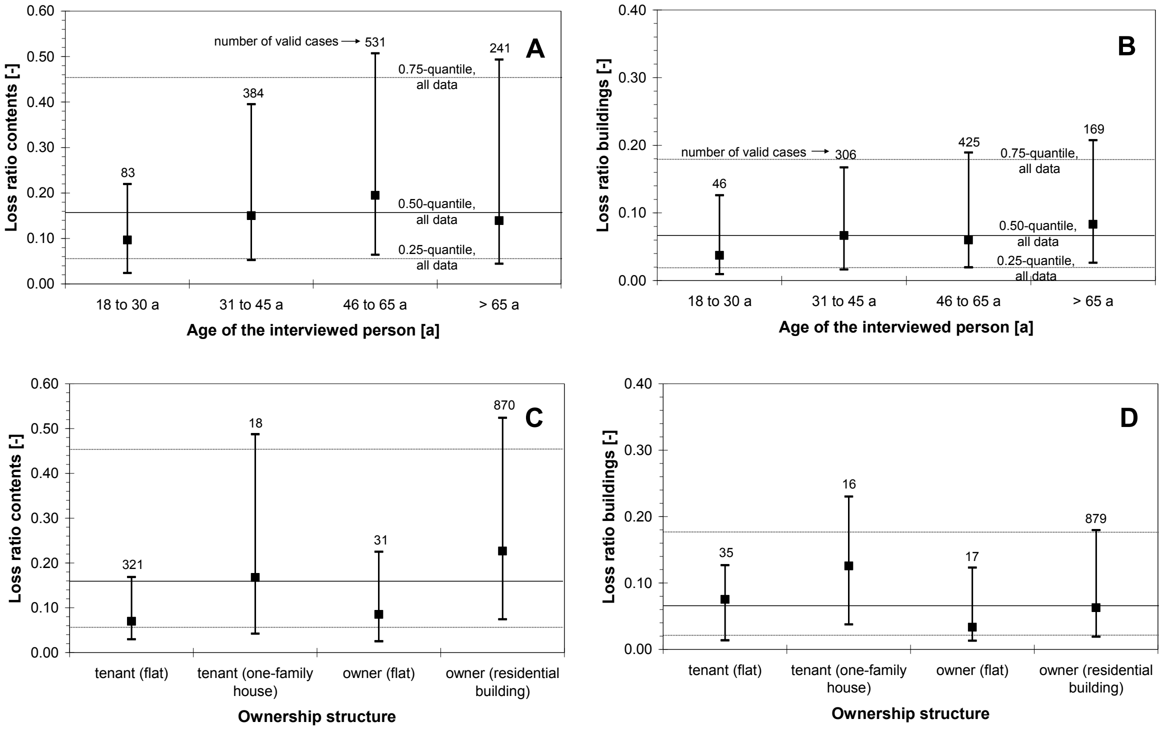

Fig. 6: 0.25-, 0.50-, and 0.75-quantiles of loss ratios of contents and buildings in relation to the age of the interviewed person (A, B), and the ownership structure of the affected household (C, D). The horizontal lines represent the 0.25-, 0.50-, and 0.75-quantiles of the loss ratios of the total data set as shown in Tab. 3.

These findings are affirmed by the variable "total number of flats in the building" that better quantifies the size of the building and widely shows the same influence pattern as the building type (Tab. 6). With regard to contents, another variable that measures the size of the affected residence is the total living area of the affected household. An equivalent for a building is its total floor space. Tab. 6 reveals that the total living area is significantly higher in the upper quartile of the absolute damage to contents as well as of the loss ratios of contents. Fig. 5A shows in more detail that there is a higher loss ratio of contents in households with a living area ranging between 80 and 180 m^2. Smaller as well as bigger residences show considerably lower loss ratios and a narrower interquartile range (Fig. 5A). Fig. 5B demonstrates that the loss ratio of buildings is considerably higher in smaller buildings. The loss ratio decreases if the total floor space of the building exceeds 120 m^2.

These results could be due to differences in the vertical distribution of the building and content values, i.e. relation between the floor plan and the number of stories. If the basement and the first floor of a given building is inundated then almost the whole building will be affected in case of a (single story) one-family house, whereas only a quarter of the building will be affected in case of a multifamily house with e.g. four stories. Moreover, apartments in multifamily houses are on average smaller than one-family houses and many affected households in multifamily houses might only have some damage in their basement but not in their apartment if they live on the second or a higher floor. That might explain the differences in content damage.

Besides, the quality of household contents and buildings might influence the extent of loss. Two variables in Tab. 6 address this issue: firstly, interviewees' assessment on a rank scale from 1 meaning "household contents/buildings are of very good quality or luxurious" to 6 meaning "household contents/buildings are of poor quality" and secondly the estimated values for contents and buildings.

In the upper quartiles of all damage items the average assessed quality of contents and buildings is significantly better. Surprisingly, this is also true for the loss ratios as can be seen in Fig. 5C and 5D, where the six ranks were classified into three classes. Actually, it was assumed that the loss ratios would eliminate the influence of the quality of affected household/building. However, both quality variables considered in Tab. 6 significantly influence the loss ratios. Thus, it has to be concluded that the true values of the buildings and household contents remain unknown and that the estimated values represent only mean estimates. However, it is difficult to query the actual values in a survey. Plausibility controls of the raw data showed that the reliability of the answers is very low since the stated damage regularly tops the denoted values.

Tab. 6 also contains a number of socio-economic variables of the affected households. In general, they display a more heterogeneous pattern than the variables discussed so far. The constitution of the affected household is addressed by the age profile of the household and its size, i.e. the number of people who permanently live in the house/apartment.

The age of the interviewed person is significantly higher in the upper quartiles of the loss ratios of both, contents and buildings. This is shown in more detail in Fig. 6A and 6B where the age was aggregated into four classes. Fig. 6A reveals that interviewed persons between 46 and 65 years were the most affected group as far as the loss ratio of contents is concerned. With regard to the building loss ratio persons younger than 31 years are less affected than the other groups (Fig. 6B). This pattern can be explained by the ownership structure of the household (see below) and the type of residence. 78% of the 46 to 65 year old people own their building which is mostly a one-family, semidetached or row house. As outlined above, these buildings experienced higher loss ratios. In contrast, more than 41% of the 18 to 30 year old people live in rented flats in multifamily houses with comparatively low loss ratios. Elderly people (i.e. older than 65 years) show an intermediate pattern: 29% live in rented flats (mostly in multifamily houses) and 67% own their (mostly one-family) house. However, the share of elderly people in a household does not differ significantly in the quartiles of all damage items (Tab. 6).

Fig. 6C and 6D illustrate the strong influence of the ownership structure on the loss ratio. Property owners witnessed larger loss ratios of contents than tenants (Fig. 6C); this pattern is inverted for the building loss ratio (Fig. 6D). It has to be noted that the building damage of rented apartments/houses could only be determined in few cases where the building owner was also interviewed.

Other variables that show very distinct differences in the upper and lower quartiles of the damage variables are the household size, the socio-economic status according to the work of Plapp (2003), which is strongly influenced by the ownership structure, the apartment and household size, as well as the monthly net income (Tab. 6). The latter can be regarded as a further indirect measure for the quality and value of household contents. Furthermore, households with a high income are more likely to own their residence. As pointed out above both aspects lead to higher loss ratios.

3.4 Interaction of different variables

To better understand the interaction between the variables that influence flood losses a PCA was performed. By this, the dimension of the data set can be reduced to a few underlying variables. Tab. 7 and 8 show the results for the variables that might influence damage to contents and buildings, respectively. Significant principal components were extracted on the basis of the Kaiser criterion and the scree plot. For the content damage variables six components should be extracted according to the Kaiser-criterion, but since there is a sharp bend in the scree plot at five components, where the eigenvalues clearly level off to the right of the plot, only five components were extracted. They account for 52.8% of the total variance. For variables concerning the building damage both criteria suggest to extract six principal components, which explain 59.3% of the total variance. After varimax rotation the component loadings show an interpretable solution. Variables with an absolute loading of 0.5 and more are the most important for the interpretation of the components.

With regard to content damage the first component is marked by high loadings of items that describe the size and the value of the affected flat/contents (Tab. 7). In the second component variables concerning the size and the age profile of the affected household obtain high loadings. The third variable is particularly marked by high loadings of flood impact items (i.e. water level, flood duration and contamination). The variable assessing the efficiency of precautionary measures (with 1 meaning “flood damage can be significantly reduced by private precaution” and 6 meaning “flood damage cannot be reduced by private precaution at all”) also has a rather high loading leading to the conclusion that people who experienced a severe flood impact do not trust very much in precautionary measures. Precaution or permanent resistance as well as flood experience/hazard awareness are the dominating variables in the fourth component, while high loadings for temporal resistance (preparedness) mark the fifth (Tab. 7).

A few variables do not show a clear correlation to one of the factors, these are: the indicator for flow velocity, the quality of household contents assessed on a scale from 1 (very good, luxurious) to 6 (very bad) and the monthly net income. The latter two items show the highest correlation with the first component summarising the flat size and value and therefore match with the meaning of the component. The flow velocity indicator shows the highest (negative) correlation with the second component what is difficult to interpret. It also shows negative loading with the fifth component indicating that emergency measures were efficiently undertaken in households where flow velocity as well as water level, which also shows a negative loading, were low (Tab. 7).

To assess which components strongly influence content damage factor scores of each component were calculated by regression, and the correlations between the factor scores and the damage variables were analysed. Tab. 7 (bottom) shows that absolute content damage correlates best with the flood impact component (3) and the component (1) that describes the value and size of the affected household. A small (negative), but significant correlation is also present for the preparedness component (5). The loss ratio of contents correlates significantly with the same components. However, the correlation is stronger for the flood impact component (3) and lesser for the first and fifth component. The second and the fourth component do not show significant correlations (Tab. 7). The same results evolve if the damage variables are included in the PCA (data not shown).

Tab. 7: Component loadings for variables that probably influence content damage (Method: Principal component analysis with varimax rotation; total variance explained: 52.75%, number of valid cases: 908). *: Bold variables are marking variables with absolute loadings ≥ 0.5. **: Bold correlation coefficients are significant on a level of 0.01 (two-sided)).

	Components (n = 908) *				
Items	**1**	**2**	**3**	**4**	**5**
Water level above top ground surface [cm]	0.02	0.00	**0.68**	0.02	-0.35
flood duration [h]	-0.06	-0.05	**0.60**	-0.12	0.32
indicator of flow velocity [-] (see section 2.3)	0.04	-0.23	-0.02	0.04	-0.14
contamination of flood water [-] (see section 2.3)	-0.03	0.02	**0.69**	0.06	-0.14
indicator of emergency measures [-] (see Tab.2)	0.07	0.08	-0.18	0.17	**0.68**
indicator building precaution [-] (see section 2.3)	0.02	0.08	-0.13	**0.51**	0.36
efficiency of private precautionary measures assessed on a scale from 1 to 6	0.11	-0.20	**0.49**	-0.08	-0.03
indicator of flood experience [-] (see section 2.3)	0.08	-0.08	-0.14	**0.78**	-0.06
knowledge of flood hazard [-]	0.03	-0.06	0.14	**0.80**	0.03
total living area of the household [m²]	**0.87**	0.15	-0.05	0.01	-0.09
quality of household contents assessed on a scale from 1 to 6	-0.24	0.18	-0.15	0.18	0.08
estimated value of contents [Euro] (see section 2.2)	**0.79**	0.14	-0.09	0.09	-0.20
age of the interviewed person [a]	0.00	**-0.70**	0.15	0.05	0.01
household size [number of persons]	0.16	**0.84**	-0.03	0.02	0.06
number of children (younger than 14 years)	0.02	**0.84**	-0.07	0.01	-0.05
ownership structure [-]	**0.65**	-0.05	0.16	0.16	0.35
monthly net income [Euro]	0.34	0.22	-0.09	-0.21	0.31
socio-economic status after Plapp (2003) [-]	**0.79**	-0.20	0.08	0.03	0.31
	Coefficient of correlation (Pearson) (n = 834) **				
absolute damage to household contents [Euro]	**0.35**	0.00	**0.39**	0.05	**-0.16**
loss ratio of household contents [-]	**0.10**	-0.06	**0.49**	0.01	**-0.09**

Tab. 8: Component loadings for variables that probably influence building damage (Method: principal component analysis with varimax rotation; total variance explained: 59.28%, number of valid cases: 707). *: Bold variables are marking variables with absolute loadings ≥ 0.5. **: Bold correlation coefficients are significant on a level of 0.01 (two-sided), underlined correlation coefficients are significant on a level of 0.05 (two-sided)).

	Components (n = 707) *					
	1	**2**	**3**	**4**	**5**	**6**
water level above top ground surface [cm]	0.02	-0.03	**0.75**	-0.04	-0.14	-0.10
flood duration [h]	0.01	-0.06	**0.51**	-0.05	0.08	0.00
indicator of flow velocity [-] (see section 2.3)	-0.01	-0.15	-0.02	-0.12	0.09	**0.56**
contamination of flood water [-] (see section 2.3)	0.03	-0.02	**0.73**	0.03	-0.06	-0.07
indicator of emergency measures [-] (see Tab. 2)	-0.01	0.04	-0.30	0.22	0.22	-0.30
indicator building precaution [-] (see section 2.3)	-0.02	0.09	-0.20	**0.56**	0.03	-0.21
efficiency of private precautionary measures assessed on a scale from 1 to 6	-0.09	-0.14	**0.50**	-0.04	0.17	0.37
indicator of flood experience [-] (see section 2.3)	-0.01	-0.07	-0.09	**0.78**	-0.03	0.06
knowledge of flood hazard [-]	-0.04	-0.07	0.15	**0.80**	-0.02	0.08
number of flats in the building	**0.87**	-0.04	0.04	-0.01	-0.15	-0.03
total floor space of the building [m²]	**0.96**	0.06	0.02	0.00	0.10	0.00
quality of buildings assessed on a scale from 1 to 6	0.01	0.13	-0.11	0.20	-0.19	**0.68**
estimated building value [Euro] (see section 2.2)	**0.95**	0.06	0.02	0.00	0.11	0.01
age of the interviewed person [a]	-0.06	**-0.73**	0.11	0.08	-0.09	0.06
household size [number of persons]	-0.01	**0.87**	-0.02	0.02	-0.01	-0.05
number of children (younger than 14 years)	0.00	**0.83**	-0.08	0.00	-0.08	0.00
ownership structure [-]	**-0.56**	-0.01	0.09	0.13	0.45	0.00
monthly net income [Euro]	0.10	0.27	-0.08	-0.06	**0.66**	-0.06
socio-economic status after Plapp (2003) [-]	-0.12	-0.27	0.02	-0.01	**0.81**	0.00
	Coefficient of correlation (Pearson) (n = 623) **					
absolute damage to buildings [Euro]	**0.31**	-0.02	**0.49**	**-0.11**	-0.09	-0.02
loss ratio of buildings [-]	**-0.14**	-0.09	**0.55**	**-0.11**	**-0.14**	-0.03

The structure of the first four components in Tab. 8 assessing the variables' influence on building damage is very similar to the pattern in Tab. 7: The first component addresses the size and the value of the affected building, the second the size and the age profile of the affected household, the third flood impact items and the fourth permanent resistance as well as flood experience/hazard awareness (Tab. 8). In the third component the variable assessing the efficiency of precautionary measures has a rather high loading as well, confirming the conclusion that people who experienced a severe flood impact do not trust very much in precautionary measures.

The fifth component is marked by high loadings of the socio-economic status of the affected household and finally the sixth component shows a high loading for flow velocity indicating the dynamic flood impact as well as for the quality of the building assessed on a scale from 1 (very good, luxurious) to 6 (very bad). This relationship needs more investigation.

The only variable that cannot be assigned to one component is the indicator for emergency measures (temporal resistance), but it is negatively correlated to the flood impact component (3) and dynamic flood impact component (6) (Tab. 8). This hints that in cases where the flood impact was high extent and efficiency of emergency measures were low.

As for the content damage, factor scores of each component were calculated by regression, and the correlations between the factor scores and the building damage variables were analysed. Tab. 8 (bottom) shows that absolute building damage also correlates best with the flood impact component (3) and the component (1) describing the value and size of the building. Small (negative), but still significant correlation exist for the preparedness component (4) and for the socio-economic status in component 5. The loss ratio of buildings correlates significantly with the first five components, among which the correlation with the flood impact component (3) is the highest (Tab. 8). Again, the same results were derived when the damage variables were included in the PCA (data not shown).

The correlation between the loss ratios with the first component is considerably lower than for the absolute damage values (cf. Tab. 7, 8). Actually it was assumed that the calculation of a loss ratio would completely level out the values of the affected elements. The analysis shows that this is not the case. As discussed in section 3.3 this might be due to shortcomings of the value estimation methods and to the vertical distribution of values, especially in multifamily houses.

The two PCAs show that flood impact variables, particularly water level, flood duration and contamination of the floodwater, are the factor mostly influencing building as well as content damage. This group of variables is followed by variables quantifying the size and the value of the affected building/flat. The important role of oil contamination became already evident during the Pentecost flood 1999 in the Danube catchment, where buildings that were inundated with oil-contaminated floodwater suffered a threefold higher loss (Müller, 2000). Therefore current flood damage models (or loss functions) that only consider water level as damage influencing factor should be substantially extended. A conceptual model that considers various characteristics of both, the flood impact and the affected building, was proposed by Nicholas et al. (2001). Further research is needed to adapt such a model to real data.

In comparison to flood and property characteristics, temporal and permanent resistance influence damage to a small fraction. The same holds for socio-economic variables (like the age profile or the socio-economic status of a household) and the dynamic flood impact (flow velocity). The minor effect of flow velocity deserves further attention since it likely plays a crucial role in mountainous regions. However, in a survey about the impact of six flood characteristics on flood damage, building surveyors in UK also assessed flow velocity to be the least important factor (Soetanto and Proverbs, 2004).

4 CONCLUSIONS

In this paper a huge data set on flood losses in private households that was gathered in the aftermath of the August 2002 flood in Germany was analysed in order to determine which factors influence flood loss and how. The comparison of the variable values in the upper and lower quartiles of four damage items (absolute content damage, loss ratio contents, absolute building damage, loss ratio buildings) as well as principal component analyses (PCA) show that flood impact variables are the factors mostly influencing building as well as content damage. This group of variables is followed by variables quantifying the size and the value of the affected building/flat. The analysis shows that building precautionary measures (retrofitting) are able to significantly reduce flood losses whereas flood warning and emergency measures partly show a contradictory picture or much less influence. In comparison to the flood impact and the characteristics of the affected property, temporal and permanent resistance influence damage to a small extent. The same holds for socio-economic variables and flow velocity. Since it is known that e.g. flow velocity plays a crucial role in mountainous regions, it should be investigated whether the same factor pattern evolves if the data set is divided in accordance to the dominating flood type shown in Fig. 2. Although there is some evidence that similar factors (flood and property characteristics) mainly influence flood losses in other regions and during other events, more research on flood data analysis is needed to proof the universal validity of the presented results. Different flood events, such as (slowly rising) river floods, flash floods, storm surges, inundation due to levee breaches or fast groundwater rise, probably cause different kinds and extents of flood losses. Therefore, future research should also analyse losses caused by different event types. Since flood damage data are scarce, efforts on data collection should be broadened.

Altogether, the results lead to the conclusion that flood loss estimation should focus on the quantification of flood impact variables, but not on the water level alone. The effect of floodwater contamination especially by oil, petrol or hazardous waste, should gain more attention. Furthermore, efforts to correctly model the type and size of the elements at risk should be enhanced. A third topic that could be integrated into flood loss models is temporal and permanent resistance. Since this is difficult to determine in an investigation area the linkage with flood experience should be further investigated. To incorporate all these factors, modern modelling techniques such as rule-based modelling or neuronal networks should be considered in the development of future flood loss models.

A better understanding of what causes flood damage and how to reliably estimate flood losses will help decision makers to better budget disaster assistance and to make risk-oriented decisions on flood defence projects. High-quality flood loss data are a premise to achieve this goal. Given the enormous variability of flood damage data guidelines for the assessment of flood damage should be developed and different methods of data compilation, such as telephone interviews or on-site surveys, should be compared. Generally, compilation and analysis of flood loss data as well as loss modelling should receive more attention in the hydrological community.

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References can be found at the end of the thesis.

Paper 6: Regionalisation of asset values for risk analyses

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Abstract

In risk analysis there is a spatial mismatch of hazard data that are commonly modelled on an explicit raster level and exposure data that are often only available for aggregated units, e.g. communities. Dasymetric mapping techniques that use ancillary information to disaggregated data within a spatial unit help to bridge this gap. This paper presents dasymetric maps showing the population density and a unit value of residential assets for whole Germany. A dasymetric mapping approach, which uses land cover data (CORINE Land Cover) as ancillary variable, was adapted and applied to regionalise aggregated census data that are provided for all communities in Germany. The results were validated by two approaches. First, it was ascertained whether population data disaggregated at the community level can be used to estimate population in postcodes. Secondly, disaggregated population and asset data were used for a loss evaluation of two flood events that occurred in 1999 and 2002, respectively. It must be concluded that the algorithm tends to underestimate the population in urban areas and to overestimate population in other land cover classes. Nevertheless, flood loss evaluations demonstrate that the approach is capable of providing realistic estimates of the number of exposed people and assets. Thus, the maps are sufficient for applications in large-scale risk assessments such as the estimation of population and assets exposed to natural and man-made hazards.

Keywords: residential buildings, population modelling, census data, loss modelling, dasymetric mapping, flood losses, Germany

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1 INTRODUCTION

The project "Risk Map Germany" was launched by the Center of Disaster Management and Risk Reduction Technology (CEDIM) and is aimed at investigating and comparing losses due to several types of natural hazards. To compare risks due to different natural and man-made disasters such as floods, windstorms and earthquakes a consistent conceptual framework of the risk analysis is needed. The framework chosen for the project "Risk Map Germany" is described in detail by Kleist et al. (2006). Here, only the basic ideas are given.

The term risk is used to describe the probability that a given loss will occur. Risk encompasses three aspects: hazard, vulnerability (susceptibility) and exposed assets or people. Whereas input data and methodologies for hazard and vulnerability assessments vary from hazard type to hazard type a uniform database of potentially exposed assets is essential for a consistent comparison of different risks (Grünthal et al., 2006). Therefore, a working group was established with the aim of developing a spatially-distributed inventory of asset values for different economic sectors in whole Germany.

As a common risk indicator, by which quantitative estimates of different risks can be compared, direct economic losses to residential buildings were chosen. Thus, Kleist et al. (2006) developed a method to estimate the asset value of residential buildings at the community level and delivered an inventory of assets for whole Germany. Like other exposure data such as population, these assets are, however, only available at spatially aggregated areas, in this case communities. Chen et al. (2004) noticed that there is a spatial mismatch between hazard and exposure data: While hazard estimates are commonly modelled at a spatially explicit raster level, exposure data are often only available at spatially aggregated and coarse areal unit levels, e.g. community districts, census tracts or postcodes. Moreover, residential buildings and population are mainly concentrated in villages, cities and along roads so that a uniform distribution of exposure data within a community or postcode is not realistic. Therefore, asset values should also be provided in a finer spatial resolution for loss modelling and risk analysis.

For the assessment of different types of natural hazards different resolutions of data are required. For example, Chen et al. (2004) showed that hailstorm risk assessments are more sensitive to the resolution of exposure data than earthquake risk assessments. For the risk assessment of insurance portfolios the requirements on data resolution of exposure data increase in the following order: windstorm, earthquake, flooding, man-made hazards (Munich Re, 2004). Whereas exposure data at the level of CRESTA (Catastrophe Risk Evaluation and Standardising Target Accumulation) zones is sufficient for windstorm and earthquake risk assessments, more accurate exposure data at the address or building level are required for flood risk assessment and particularly for the assessment of man-made hazards (Munich Re, 2004). CRESTA-zones have become a widely accepted standard in the international insurance industry (see www.cresta.org). In Germany, CRESTA-zones correspond to the level of five-digit postcodes (CRESTA, 2004).

A map with building specific assets cannot be provided on a nationwide scale as it is required for the project "Risk Map Germany". In order to bridge the gap between aggregated census data and geocoded data, land use information is used to disaggregate census data. This type of mapping information is called dasymetric mapping and traces back to the work of Wright (1936). The aim of this paper is to adapt a dasymetric mapping algorithm for the disaggregation of population and asset values in Germany and to provide countrywide dasymetric maps of these variables. Before presenting the methods and results, a short overview of relevant literature on dasymetric mapping is given in the next section. Moreover, a validation of the method is performed within the context of risk analyses. Since flood risk assessments are rather sensitive to data resolution, the validation is done with a number of flood scenarios.

2 LITERATURE REVIEW ON DASYMETRIC MAPPING

A dasymetric map depicts quantitative areal data using boundaries that divide the mapped area into zones of relative homogeneity with the purpose of best portraying the underlying statistical surface (Eicher and Brewer, 2001). Most dasymetric mapping methods are mass-preserving, i.e. the total of the mapped variable in each origin zone is kept after disaggregation. Dasymetric zones are generated by using ancillary information. According to MacEachren (1994), data representation via dasymetric mapping can be classified as a transition between smooth and stepped statistical surfaces.

In most of the investigations land cover data are used as ancillary data (e.g. Fisher and Langford, 1995; Yuan et al., 1997; Martin et al., 2000; Eicher and Brewer, 2001; Mennis, 2003; Holt et al., 2004). An exception is the work of Chen et al. (2004), who used street buffers to roughly estimate inhabited areas in postcodes.

There are different methods of dasymetric mapping using land cover data (see Eicher and Brewer, 2001 for details and further references): the binary method, the three-class method, the limiting variable method and regression methods. Table 1 provides an overview of the different mapping techniques.

With the **binary method** 100% of the census data are assigned to exclusive land cover classes, such as urban areas or agricultural areas, whereas no data is assigned to other land cover classes like forest or water. The binary method is a specialised form of the limiting variable method (see below) and was originally developed by Langford et al. (1991) as a mapping technique.

Tab. 1: Overview of dasymetric mapping techniques.

Method	Characteristics	Example
Binary method	Population is only assigned to exclusive land cover types.	100% of the population is assigned to the land cover type “urban area”.
Three-class method	Population is assigned to three different land cover type by a fixed weighting scheme.	70% of the population is assigned to the land cover type “urban area”, 20% to “agricultural area/woodland” and 10% to “forested area” (Eicher and Brewer, 2001).
Limiting variable method	Population is assigned to different land cover types by areal weighting considering thresholds of maximum population density per land cover type.	The maximum population density is set to 50 inhabitants per square kilometre for land use type “agricultural area/woodland” and to 15 for “forested area” (Eicher and Brewer, 2001).
Regression	Population density per land cover type is determined by regression analysis of equation (1) in section 3.2.	See e.g. Yuan et al. (1997)

For the **three-class method** a weighting scheme is used to assign population or other census data to three different land cover classes within each census district, e.g. urban, agricultural/woodland and forest. Other land cover classes like water receive no data. There are two major weaknesses of this method: the weights are subjectively determined and the method assumes a uniform distribution of land cover, i.e. it does not account for the actual area that is covered by each land cover class within a given census district (Eicher and Brewer, 2001; Mennis, 2003). Mennis (2003) proposes an algorithm that overcomes the second problem.

The **limiting variable method** was described by McCleary (1969). In this method, data is firstly assigned to all inhabitable areas by simple areal weighting. In the next step, thresholds of maximum density that are derived from land use data or expert judgement are set for particular land uses. These thresholds determine modifications of the data distribution: If a polygon density exceeds its threshold, the threshold density is assigned to this polygon and the remaining data are distributed evenly among the remaining zones in the census district (Gerth, 1993 cited in Eicher and Brewer, 2001).

As a fourth type of method, **multivariate regression** is performed to examine the correlation between population counts from census and land cover types assuming that the total population of a census district is the sum of the products of population densities and total areas of each land cover type in the district (e.g. Langford et al., 1991; Yuan et al., 1997). To ensure that the total population within a census district is preserved, a correction factor, i.e. the ratio of the total predicted population within one census district and the census data of that district, is used to adjust the estimates (Flowerdew and Green, 1989). Gallego (2001) developed a regression-like method that is based on data from two levels of aggregation and an iterative algorithm by which the coefficients that describe the population density per land cover type are determined. Gallego (2001) further improved the method by distinguishing different types of communities (see below).

A number of studies deal with the comparison of different methods. However, Martin et al. (2000) emphasise that one of the key obstacles to the evaluation of dasymetric mapping techniques is the lack of definitive high resolution population data. Since the model performance is strongly influenced by the resolution and accuracy of the input data, input data quality is more important than algorithmic details (Martin et al., 2000).

In comparison to areal weighting and to different regression methods the dasymetric binary method is the most accurate in the investigation of Fisher and Langford (1995). Binary dasymetric mapping also outperforms an approach in which population is redistributed in proportion of a cell's distance to the centroids of the census districts (Martin et al., 2000). In the investigation of Eicher and Brewer (2001) the limiting variable method performs best in comparison to the binary as well as the three-class method. The most recently developed methods of Gallego (2001) and Mennis (2003) have not been compared so far.

Most of the studies focus on the distribution of population. Further research should be done to remodel other socio-economic variables and to assess the reliability of the results (Yuan et al., 1997). Therefore, the aim of this paper is to adapt the mapping approach of Gallego (2001) for the regionalisation of population and asset values in Germany and to provide countrywide dasymetric maps of these variables. Moreover, a validation of the method is performed using a number of flood scenarios.

3 DATA AND METHODS

3.1 Input data

For the application of the mapping approach of Gallego (2001) census data with boundaries of the census tracts as well as land use data are necessary. In the CEDIM project "Risk Map Germany" the following data sources have been used:

Census data were provided by INFAS Geodaten (2001). These data contain geometric information in boundary lines as well as census information about, e.g., population, households or absolute and relative amount of different building types. The data are available in two spatial units which are defined by the administrative boundaries of the communities and the five-digit postcodes, respectively. Both topologies do not depend on each other and are thus partly incongruent. In general, the community level is used for the risk assessments in CEDIM and thus for the disaggregation of census data. The data on postcode level is used to validate the disaggregation of the population done on the community level.

Since the overall goal of this investigation is to perform a suitable dasymetric mapping approach to the estimates of assets for residential buildings per community given by Kleist et al. (2006), these data are also used as input.

CORINE (CoORdination of INformation on the Environment) Land Cover data (CLC) for Germany - funded by the German Federal Environmental Agency and by the European Union - is used as ancillary dataset to perform dasymetric mapping. The CLC dataset gives a European wide overview of land use in 44 categories. The data evaluation is based on satellite imagery interpretation with a defined minimum size for different areas (25 hectares), so CLC areas show a high degree of generalisation. The used dataset reflects the land use pattern in the year 2000 (Mohaupt-Jahr and Keil, 2004).

3.2 Method for regionalisation of aggregated data - dasymetric mapping

Gallego (2001) developed a model for the distribution of census population on the basis of the CLC dataset for whole Europe. It is based on the approach that the population in a community m can be described as the sum of the areas of different land cover classes in that community multiplied by a respective population density:

$$X_m = \sum_c S_{cm} Y_{cm} \qquad (1)$$

$$Y_{cm} = U_c W_m \qquad (2)$$

X_m: population in community m

S_{cm}: area of land cover class c in community m

Y_{cm}: population density of land cover class c in community m

U_c: quasi-median population density of land cover class c (determined by an iterative algorithm)

W_m: correction factor for community m

The population density consists of a quasi-median population density and a correction factor. The correction factor W_m ensures that the total population of a community will be correctly estimated by this approach, and is calculated by the ratio of the census data of that community and the total predicted population within one community using the coefficients U_c in Table 2. The coefficients U_c are given in Gallego (2001) distinguishing six land cover classes and three types of communities (Tab. 2). The land cover classes are derived by aggregating the original 44 CLC classes into the following categories: 1) continuous urban areas, 2) urban areas (including industrial, commercial, and transport units as well as artificial non-agricultural vegetated areas for recreational purposes), 3) arable land, 4) permanent crops and heterogeneous agricultural areas, 5) pastures, 6) forests and areas covered by natural vegetation. All other land cover types such as water, wetlands, open spaces with little or no vegetation as well as mine, dump and construction sites are classified as uninhabitable.

Three types (strata) of communities are derived by comparing the population density of a community with the population density at the corresponding regional level. For this purpose the EU Nomenclature of Territorial Units for Statistics (NUTS) is used. NUTS is a hierarchical classification, that subdivides each EU Member State into a number of NUTS1 regions, each of which is in turn subdivided into a number of NUTS2 regions etc. In Germany, the NUTS1 level refers to the federal states (*Bundesländer*), the NUTS2 level to regions and the NUTS5 level to communities (Eurostat, 2005).

Gallego (2001) defines three types of communities: The first stratum consists of communities (NUTS5) with an overall population density that is twice as high as the population density of the corresponding NUTS2 region or even higher. In contrast to Gallego (2001), communities with more than 50,000 inhabitants are generally assessed as densely populated and are thus assigned to stratum 1 in this study.

The second stratum includes communities (NUTS5) with an overall population density that is lower than the twofold population density of the corresponding NUTS2 region. In addition, urban areas (i.e. land cover classes 1 or 2) must be present in the community.

Tab. 2: Quasi-median population density U_c per land cover type and community type; U_c was determined by an iterative algorithm in Gallego (2001).

Land cover type	Quasi- median population density per community type [Inhabitants/km²]		
	Stratum 1	Stratum 2	Stratum 3
Continuous urban areas	1445.9	947.4	0
Urban areas	619.1	622.4	0
Arable land	10.2	17.4	32
Permanent crops, heterogeneous agricultural areas	15.4	30.9	69.3
Pastures	5.1	11.3	22.8
Forest & natural vegetation	3.3	5.2	8.6

Tab. 3: Number of communities and inhabitants per community stratum in Germany. In stratum 4 large uninhabited areas that are modelled as independent polygons in the INFAS geo-dataset are summarised.

Community stratum		Number of communities	Number of inhabitants per community			
			Mean	Standard deviation	Minimum	Maximum
1	Densely populated	1203	37483	134663	257	3388434
2	Populated	8977	3997	5951	35	49485
3	Sparsely populated	3236	452	407	2	4459
4	Uninhabited areas	74	0	0	0	0
	Sum	13490				

The third stratum contains communities (NUTS5) with an overall population density that is lower than the twofold population density of the corresponding NUTS2 region and the community area shows NO urban areas in the CLC dataset (i.e. no areas of the land cover classes 1 or 2).

In this study, a fourth stratum is introduced for large uninhabited areas that do not belong to any community in Germany and are modelled as independent polygons in the INFAS geo-dataset. Such areas can be found in mountainous regions (cf. Fig 3A). In this stratum all coefficients U_c are zero.

The number of communities in each stratum and the population statistics in Germany are summarised in Table 3.

After reclassifying the original CLC dataset into the six land cover classes and after determining the stratum of each community, a correction factor Wm is calculated for each community within the GIS ArcView by the following equation:

$$W_m = \frac{X_{mINFAS}}{\sum_c S_{cm} U_c} \qquad (3)$$

W_m: correction factor for community m

X_{mINFAS}: population in community m according to INFAS Geodaten (2001)

S_{cm}: area of land cover class c in community m

U_c: quasi-median population density of land cover class c (determined by an iterative algorithm)

For the regionalisation of population data, the community boundaries are first intersected with the boundaries of the reclassified CLC dataset. The population densities U_c and the correction factors W_m are then assigned to each land cover class and community, respectively. The population density of a land cover polygon is determined by equation (2). The total population within a polygon is estimated by multiplying the Y_{cm} with the respective polygon area.

A regionalisation of the asset values of residential buildings provided by Kleist et al. (2006) is performed by multiplying the estimated population of a polygon with the per-capita asset of residential buildings of the corresponding community. For the purpose of risk analysis a map representing unit values for residential buildings in Euro per square meter is more useful. Therefore the asset value per polygon is divided by the polygon area. The mapping procedure is outlined in Fig. 1.

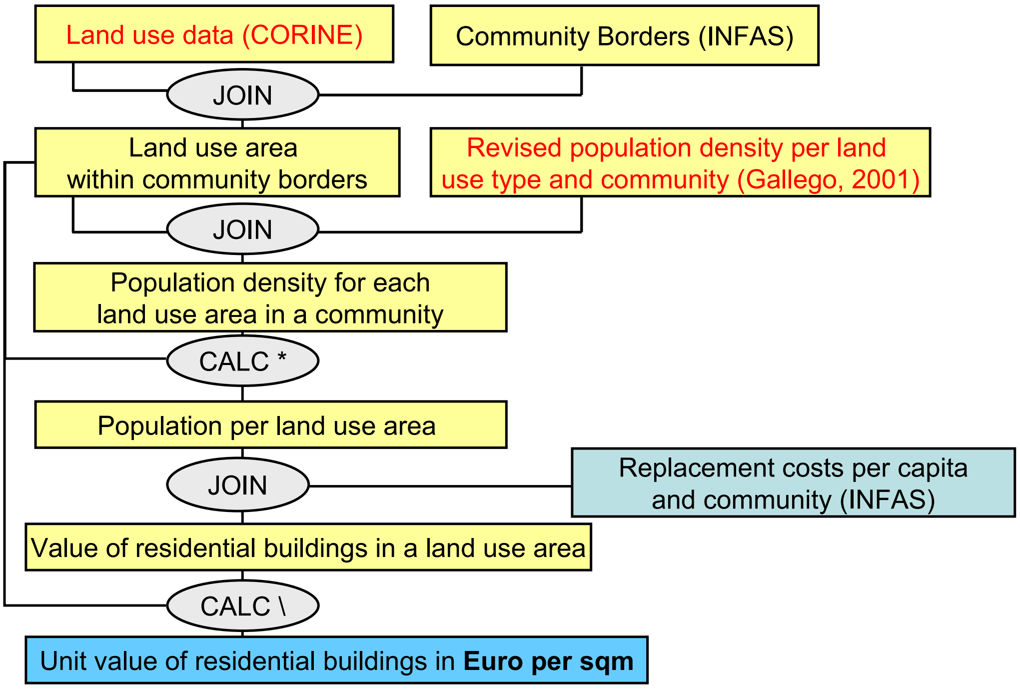

Fig. 1: Map model for regionalisation of asset values (dasymetric mapping).

3.3 Model Validation

The adapted method of Gallego (2001), i.e. the regionalisation of population and assets, is validated by two approaches. In a first attempt, the disaggregated map of population density is used to estimate the total population in five-digit postcodes. The "real" population per postcode is also provided by INFAS Geodaten (2001). As mentioned above, the topologies of community boundaries and postcodes are independent from each other. The error of the population per postcode is mapped and analysed statistically.

In a second approach the regionalisation method is validated by intersecting the disaggregated population density map and the dasymetric map of the unit residential values with flood lines of real flood events. By means of intersection, the number of affected people and the amount of affected residential assets can be estimated. A rough loss estimation is performed, as well. These estimates are then compared with figures given by the authorities. This procedure is also performed for the aggregated data on community level in order to analyse whether better results are achieved with disaggregated data.

Since the data used for the estimation and regionalisation of residential values refers to the year 2000, flood scenarios around this reference year are chosen for validation. Two flood events took place along the river Danube in 1999 and along the rivers Elbe and Danube in 2002, respectively. The inundation areas were provided by several German environmental and cartographic agencies and are shown in Fig. 2.

To estimate the assets at risk due to these flood events, the values of Kleist et al. (2006) have to be adjusted by construction indices of the year of the flood. Construction indices are published by the Federal Statistical Agency (Statistisches Bundesamt, 2004). For the years 1999 and 2002, the original assets have to be corrected by a factor of 0.997 and 0.999, respectively.

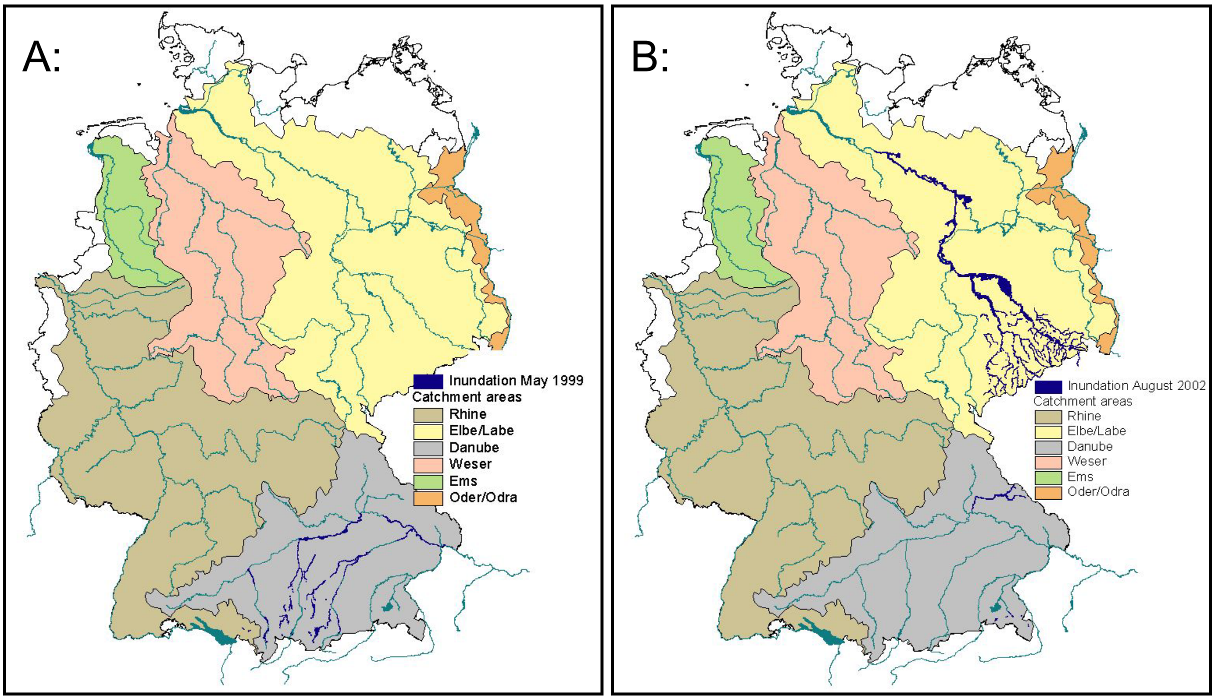

Fig. 2: Flooded areas in Germany during the Pentecost flood in May 1999 (A) and during the flood of August 2002 (B). (Data sources: ATKIS®DLM1000, VG250, Flood lines of the Elbe flood on the basis of satellite picture © Federal Agency of Cartography and Geodesy 2003; Flood plain of the Mulde river, UFZ Leipzig 2003; Inundated areas in Saxony during the flood 2002: Saxon Agency of Environment and Geology, Water resources management information system of the Bavarian water resources management office, 2004, www.bayern.de/lfw).

Tab. 4: Areas of land cover types according to reclassified CORINE Land Cover data in Germany and estimated population per land cover type following the model of Gallego (2001).

Land cover type	Area [km²]	% Area	Estimated population	% Estimated population
Continuous urban areas	231.7	0.1%	1 919 083	2.3%
Urban areas	27 412.8	7.7%	69 082 677	83.8%
Arable land	136 825.0	38.3%	5 963 433	7.2%
Permanent crops, heterogeneous agricultural areas	23 127.3	6.5%	2 231 911	2.7%
Pastures	54 052.8	15.1%	1 706 884	2.1%
Forest & natural vegetation	109 025.0	30.5%	1 536 091	1.9%
Uninhabited areas	6 604.7	1.8%	0	0.0%
Sum	357 279.3	100.0%	82 440 079	100.0%
Total population according to INFAS			82 440 309	
Absolute error			-230	
Relative error			-0.0003%	

4 RESULTS AND DISCUSSION

4.1 Population density

The general composition of the aggregated land cover classes in Germany on the basis of the CLC dataset and the total amount of population which is assigned to each land cover class by the adapted algorithm of Gallego (2001) are summarised in Tab. 4. Due to the introduction of the correction factors W_m the total population is estimated correctly (see equation 3).

Urban areas cover less than 8% of the whole area in Germany, but more than 80% of the population are assigned to this land cover class. In contrast, arable land and forest cover more than 30% of the area each, but only 7% and 2% of the population are assigned to these classes, respectively (Tab. 4). These results are consistent with those of Gallego (2001).

Figure 3 shows the spatial distribution of population density in Germany as well as the differences between a choroplethic (Fig. 3A) and a dasymetric (Fig. 3B) mapping approach. It is obvious that a high population density exists around the big cities e.g. Hamburg, Berlin, the Ruhr area (around the cities of Dortmund, Essen, and Duisburg), Köln (Cologne), Frankfurt, Stuttgart and München (Munich). In comparison to the choroplethic map in Fig. 3A, settlement patterns and agglomeration areas are highlighted in more detail by the dasymetric mapping approach in Fig. 3B.

4.2 Distribution of assets

On the basis of the population distribution shown in Fig. 3B the asset values of Kleist et al. (2006) are distributed by multiplying the per-capita asset value for residential buildings of a community with the number of inhabitants per polygon of the dasymetric map in that community shown in Fig. 3B. To better compare the results, the total asset values are transformed into unit values per square meter. The results are shown in Fig. 4A as a choroplethic map per community and in Fig. 4B per polygon of the dasymetric map. Due to the algorithm, the spatial pattern of the asset distribution correlates well with the pattern of the population density presented in Fig. 3B. Again, the dasymetric mapping approach imparts a more detailed picture of the asset distribution.

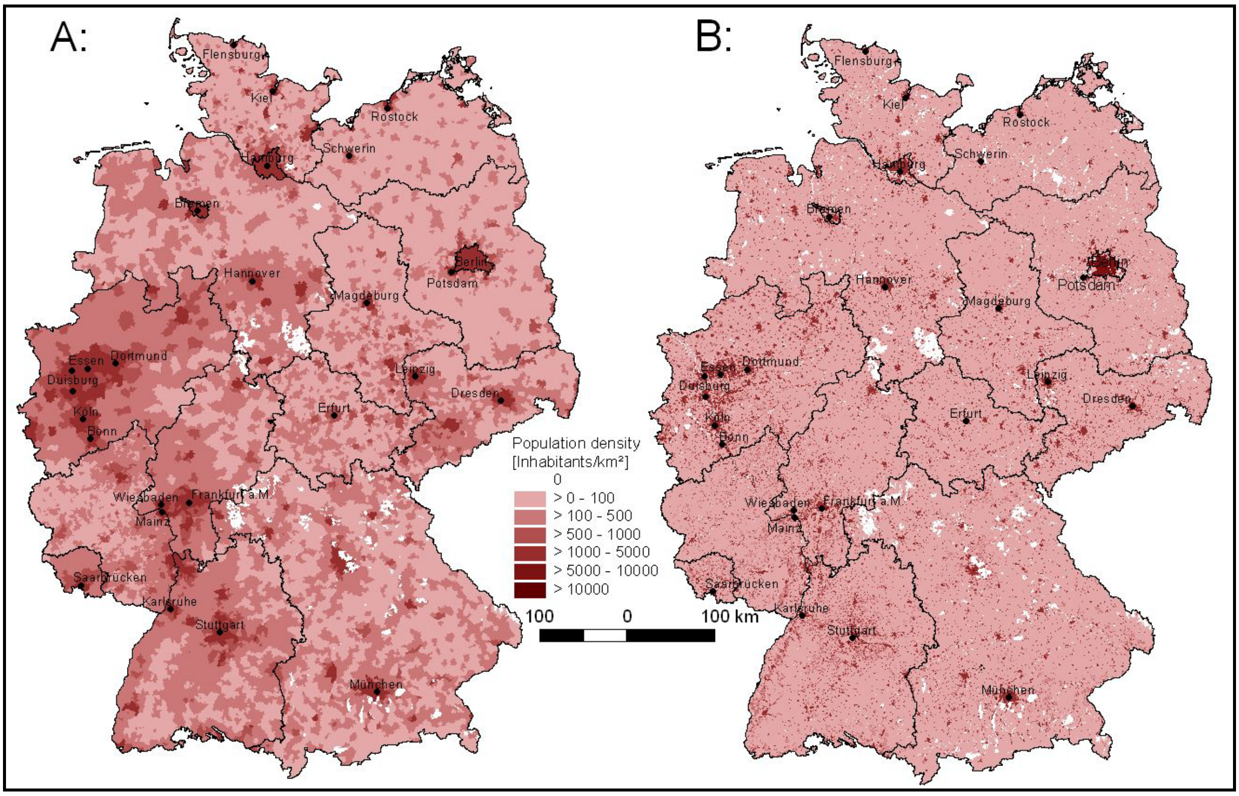

Fig. 3: A: Choroplethic map of population density based on INFAS Geodaten (2001) per community. B: Dasymetric map of population density based on INFAS Geodaten (2001), CORINE Land Cover 2000 and the adapted mapping algorithm of Gallego (2001). Data are given in number of inhabitants per square kilometre.

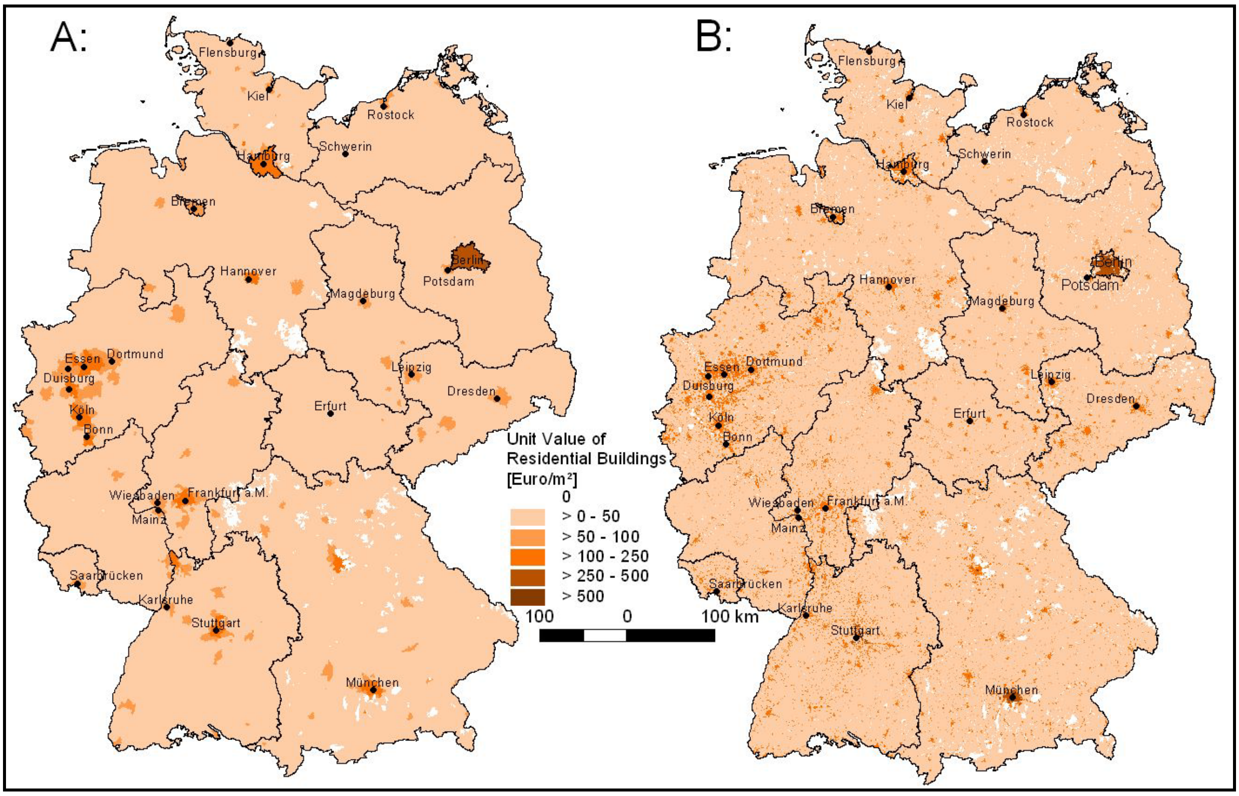

Fig. 4: A: Choroplethic map of assets of residential buildings according to Kleist et al. (this issue) per community. B: Dasymetric map of assets of residential buildings based on INFAS Geodaten (2001), CORINE Land Cover 2000, the adapted mapping algorithm of Gallego (2001) and the per-capita values calculated by Kleist et al. (2006). Data are given in asset value of residential buildings per square meter.

4.3 Model validation and application

As outlined above, the validation of the model is performed by two approaches: firstly, by estimating population in postcodes and secondly, by using the maps for flood loss evaluations.

In Fig. 5 the percentage of error in estimating population in postcodes is shown. The error is defined as the difference between the population per postcode given by INFAS Geodaten (2001) and the population per postcode estimated from the disaggregated population shown in Fig. 3B. Thus, positive (red) error values in Fig. 5 indicate an underestimation of the "real" population given by INFAS, whereas negative (blue) values indicate an overestimation of the "real" population. The mean error amounts to -3%, i.e. on average the population in postcodes is slightly overestimated if the estimate is derived from the dasymetric population map shown in Fig. 3B. The overestimation is due to the fact that the area of the postcodes was not considered in this calculation. If an area-weighted mean is calculated, the mean estimation error amounts to -0.0003% that was also indicated as estimation error in Table 4.

It is obvious that large errors particularly occur in the regions of the big German cities (Fig. 5). This can be explained by two aspects. At first, the postcodes in the big cities are much smaller than the corresponding community area. For example, the community/city of Berlin is divided into 190 postcodes, Hamburg into 101, München (Munich) into 74, Düsseldorf into 38, and Essen into 32. On the other hand, several rural communities are often summarised into one postcode, e.g. the largest postcode "Templin" covers 20 communities. Altogether, for the 13490 communities in Germany only 8257 postcodes exist. Therefore, the validation process has different conditions for rural and urban areas. Whereas the population of postcodes in rural areas tends to be summarised from several communities, the population of postcodes in urban areas has to be estimated from a fraction of the corresponding community. Thus, in urban areas a higher accuracy of the disaggregated data is requested.

The land use composition is a second aspect that is important for this topic. For all postcodes with low or high estimation errors the mean composition of the seven aggregated land cover classes is shown in Table 5. In postcodes with a low population estimation error of up to ±10%, the composition of the land cover classes corresponds approximately to the average composition of all postcodes except for urban areas. In contrast, the postcodes with a high underestimation, i.e. with a population estimation error of less than -50%, are characterised by a very high percentage of urban areas. Other land cover classes are clearly underrepresented (Tab. 4). That means that densely populated areas in the city centres are not correctly modelled by the adapted approach of Gallego (2001). Fig. 5 illustrates that postcodes with high underestimations are often adjacent to areas with high overestimations. Table 5 shows that postcodes with a high overestimation, i.e. with a population estimation error of more than 50%, still contain a share of urban areas above average. However, there is also a considerable amount of arable and forested land. Altogether, it must be concluded that the algorithm tends to underestimate the population in urban areas and to overestimate other land cover classes.

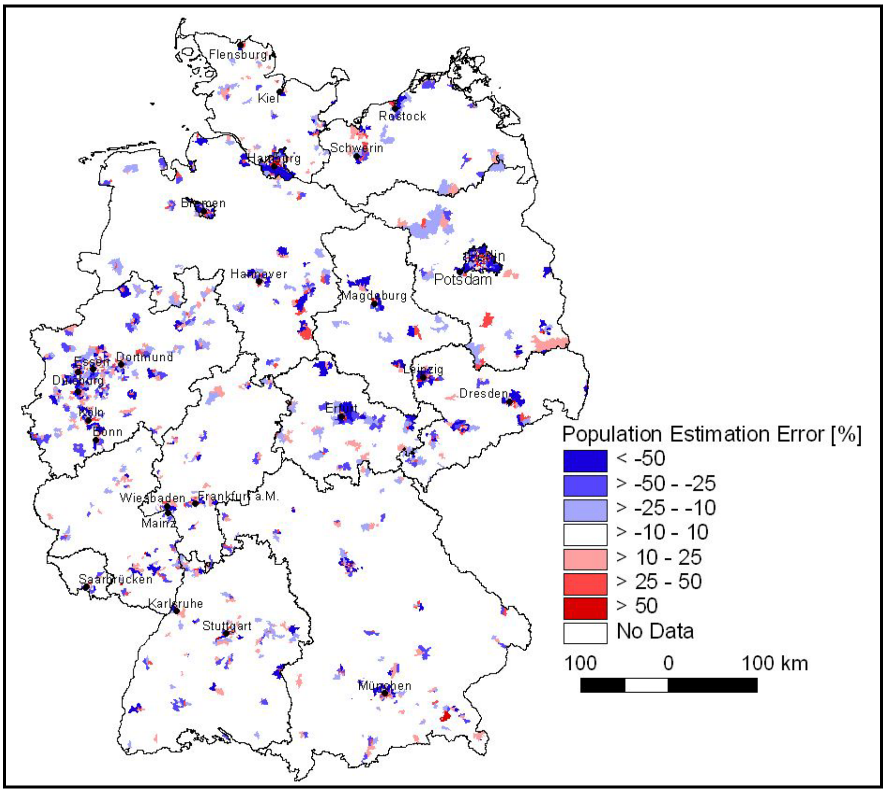

Fig. 5: Relative population estimation error in per cent per postcode. The error is defined as: error = (population per postcode as given by INFAS Geodaten (2001)) - (population per postcode as estimated on the basis of Fig. 3B); blue: overestimation of the INFAS-population; red: underestimation of the INFAS-population.

Tab. 5: Average composition of land cover classes in postcodes with different population estimation errors.

Land cover type	Postcodes with a population estimation error of < -50% (underestimation)	Postcodes with a population estimation error of > 50% (overestimation)	Postcodes with a population estimation error of ± 10%	All post-codes
Continuous urban areas	8%	3%	0%	1%
Urban areas	78%	45%	10%	18%
Arable land	4%	22%	34%	31%
Permanent crops, heterogeneous agricultural areas	1%	3%	9%	8%
Pastures	2%	7%	15%	14%
Forest & natural vegetation	3%	16%	29%	26%
Uninhabited areas	3%	4%	2%	2%
Number of postcodes	169	282	6559	8257

Tab. 6: Estimates of the number of exposed people and residential assets for two flood events in Germany as well as rough estimates of the losses to residential buildings (put in parentheses) assuming an average loss ratio of 12.3% according to the work of Thieken et al. (2005).

Flood Event	Federal State	Estimated number of affected people		Estimated sum of exposed assets of residential buildings (and estimated loss) in the year of the flood [million euro]	
		Aggregated data	Disaggregated data	Aggregated data	Disaggregated data
August 2002	Saxony	159212	212155	7490 (921)	9926 (1221)
	Saxony-Anhalt	129655	54743	5354 (658)	2268 (279)
	Bavaria	9106	11149	494 (61)	619 (76)
May 1999	Bavaria	106329	69444	5507 (677)	3624 (446)

Tab. 7: Number of affected people, total damage and damage to residential buildings during two flood events in Germany as quoted by the authorities (Sources: Deutsche Rück, 2000; IKSE, 2004; SSK, 2004).

Flood Event	Affected Federal State	Number of affected people	Total damage	Damage to residential buildings
August 2002	Saxony	No data	€ 8700 million	€ 1706 million
	Saxony-Anhalt	No data	€ 1187 million	€ 246 million*
	Bavaria	No data	€ 198 million	No data
May 1999	Bavaria	100 000	€ 393 million	€ 98 million

* data include damage to household contents

In the second validation procedure two flood events that occurred in May 1999 (Fig. 2A) and August 2002 (Fig. 2B), respectively, are analysed. Both aggregated census data and data disaggregated by dasymetric mapping were used to estimate the number of exposed people and residential assets. The results are summarised in Tab. 6. The values provided by the authorities are given in Tab. 7.

The number of affected people can only be compared for the Pentecost flood 1999 in Bavaria. Surprisingly, the number of affected people given by the authorities is better estimated on the basis of aggregated data. However, also the estimate with disaggregated data is in a similar order of magnitude (Tab. 6 and Tab. 7).

With regard to the residential assets, the values in Tab. 6 and Tab. 7 cannot be compared directly, since in Tab. 7 the losses that occurred to residential buildings are given, whereas in

Tab. 6 the total sum of exposed assets is calculated. Therefore, an overall loss ratio of 12.3% which was the mean loss ratio among more than 1000 residential buildings during the August 2002 flood in a survey of Thieken et al. (2005) was assumed to roughly estimate the damage to residential buildings (Tab. 6). Although it was not expected that the losses in all affected areas would be modelled correctly with a uniform loss ratio, this simple approach was chosen to compare the feasibility of aggregated and disaggregated data.

With this simple loss estimation, the magnitude of losses to residential buildings in the three most affected federal states Saxony, Saxony-Anhalt and Bavaria is surprisingly well estimated for the August 2002 flood if disaggregated data are used (compare Tab. 6 and Tab. 7). The use of aggregated data leads to a clearer underestimation of losses for Saxony and a clearer overestimation for Saxony-Anhalt than the use of disaggregated data. Both methods tend to overestimate the losses in Bavaria. This might be due to the fact that the 2002 flood event was less severe in Bavaria. Thus, a mean loss ratio of 12.3% is probably too high for this region. On the contrary, the value might be too low for Saxony, the most affected state during the August 2002 flood. Thus, a more sophisticated loss estimation model should improve the results.

The good results for the August 2002 flood cannot be reproduced for the flood in 1999. Both methods lead to an enormous overestimation of loss (compare Tab 6 and Tab. 7). Also in this example, however, the results with aggregated data are inferior to those with disaggregated data. In contrast, the number of affected people is estimated quite well (see above). Altogether, this flood event needs further investigation.

Considering the fact that the loss estimation was done with a very simple assumption, the results show that the approach is capable of estimating a realistic number of exposed people and residential assets. In most of the cases, the use of disaggregated data provides better results than the use of aggregated data. For a thorough validation, however, better loss estimation models have to be applied and further flood events have to be analysed.

5 CONCLUSIONS

In order to provide exposure data that meet the demands of large-scale risk assessments a dasymetric mapping approach was successfully performed. The approach of Gallego (2001) is based on a regression-like model that uses CORINE land cover data as ancillary variable to distribute census population. In this study, the model was adapted to also map asset values of residential buildings and was then applied to all of Germany. As a result maps showing the population density and a unit value of residential assets can be presented for whole Germany. These maps can be used as input data for the estimation of population and assets at risk. The results were validated in two ways.

From the validation it has to be concluded that the algorithm tends to underestimate the population in urban areas and to overestimate population in other land cover classes. Therefore, high errors might occur, especially in urban areas. Nevertheless, good results were achieved when estimating people and assets exposed to the August 2002 flood that hit large parts of Germany. Such satisfying results could not be reproduced for a flood that occurred in 1999 in Southern Germany. All things considered, however, this approach does yield realistic estimates of exposed people and vulnerable assets.

For a thorough validation further flood events and scenarios of other natural disasters, e.g. windstorms or earthquakes, should be analysed. Future analyses should include more sophisticated loss models. Besides, upcoming research may lead in two other directions: First, the method used here should be evaluated in comparison to other dasymetric mapping methods. As a second direction of research, further possible applications of the presented maps should be investigated. In case of a disaster there is a need for quick and reliable loss estimates in order to provide enough resources for loss compensation and recovery. The presented maps could serve as an input to such a system. Research on this topic would be important for the general improvement of current disaster management.

Acknowledgements

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References can be found at the end of the thesis.

Paper 7: Development and evaluation of FLEMOps – a new *F*lood *L*oss *E*stimation *MO*del for the *p*rivate *s*ector

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Abstract

The estimation of flood losses is an essential component for risk-oriented flood design, risk mapping or financial appraisals in the reinsurance sector. However, only simple models, e.g. stage-damage curves, have been used frequently. Further, the reliability of flood loss and risk estimates is fairly unknown, since flood loss models are scarcely validated.

In the aftermath of flooding in August 2002 large data sets of flood losses were collected at affected properties in Germany. These data were used to derive multi-factorial loss models. This paper presents FLEMOps - the Flood Loss Estimation Model for the private sector, which estimates direct monetary flood losses at residential buildings and household contents considering water level, building type and building quality. In an additional model stage (FLEMOps+), the effects of private precautionary measures as well as of the contamination of the floodwater can be quantified. Together with census data and land use information the model is adapted for applications on the meso-scale.

Further, different data sets of repair costs at single buildings and in whole municipalities were used to validate loss estimates on the micro- as well as on the meso-scale. First results show that the model FLEMOps+ outperforms simple stage-damage-functions.

Keywords: damage estimation, precaution, contamination, model validation, flood losses

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1 INTRODUCTION

Risk-oriented flood design, comparative risk analyses, risk mapping as well as financial appraisals of probable (maximum) losses require reliable estimations of flood losses. A central idea in current flood loss estimation is the concept of loss functions, in which the direct monetary loss is related to the type or use of the building and the inundation depth at that building. These functions are an internationally accepted standard approach for assessing urban flood losses (Smith, 1994). However, loss functions may have a large uncertainty (see Merz et al., 2004), since flood loss is probably influenced by many more factors among which are flow velocity, flood duration, contamination, building characteristics, private precautionary measures and flood warning (e.g. Smith, 1994; Penning-Rowsell, 1999; Kreibich et al., 2005a; Thieken et al., 2005). These aspects are, however, scarcely included in flood loss models.

Furthermore, the reliability of flood loss and risk estimates is fairly unknown, since flood loss models are rarely validated. This might be due to limited or missing observations and data about (extreme) flood scenarios. Especially, loss data are rarely gathered, (initial) repair cost estimates are uncertain and data are not updated systematically (Downton and Pielke, 2005). Low standardisation of the collection of flood losses might cause problems with data quality. For example, assessments of flood losses and flood characteristics (water level, velocity, etc.) at affected properties are in most instances based on subjective perceptions of building surveyors and may therefore be prone to variation (Soetanto and Proverbs, 2004).

To improve and validate the hitherto existing methods for flood loss estimation, the project "Methods for the Evaluation of Direct and Indirect flood losses" (MEDIS) was launched in 2005. Model development has been undertaken in several sectors, such as the private, commercial, agricultural and public sector (e.g. damage to transport). The goal of this paper is to present a new model for the estimation of losses in the residential sector and its validation. The following conditions had to be met during the model development:

1. The new model should take into account more influencing factors, not only the water level.
2. The model is to be based on loss ratios (instead of absolute losses) so that a combination with various asset stocks (e.g., total asset of residential buildings, insured assets/portfolios) is possible.
3. Different scales of model application (such as buildings and land use units) should be enabled.
4. Finally, the model is to be evaluated by different validation techniques.

2 MODEL DEVELOPMENT: DERIVATION OF LOSS FUNCTIONS

2.1 The empirical data base

After a severe flood event that hit the rivers Elbe, Danube and some of their tributaries in August 2002, flood-affected residents were surveyed by computer-aided telephone interviews. The questionnaire contained about 180 questions addressing the following topics: flood impact, contamination of the flood water, flood warning, emergency measures, evacuation, cleaning-up, characteristics of and losses to household contents and buildings, recovery of the affected household, precautionary measures, flood experience as well as socio-economic variables. A detailed description of the survey concerning the flood in 2002, data processing and the development of indicators can be found in Kreibich et al. (2005a) and Thieken et al. (2005). For example, the total asset values of the affected buildings were estimated according to the VdS guideline 772 1988-10 (Dietz, 1999). By this, loss ratios, i.e. the relation between the building loss and the corresponding total asset value, could be calculated. On the basis of these data and the results of Thieken et al. (2005) a new model for the estimation of flood losses was developed.

2.2 Derivation of micro-scale loss functions

Five factors are considered in the Flood Loss Estimation MOdel for the private sector (FLEMOps). For the model development, the surveyed data of each influencing variable were classified as shown in Tab. 1. The first three variables listed in Tab. 1 were used to derive a core loss model, i.e. for all sub data sets (classes) mean loss ratios per loss type (building, contents) were calculated. The model for building losses is illustrated in Fig. 1.

In a second model stage (further called FLEMOps+), scaling factors that quantify the overall effect of contamination and precaution can be considered (see Tab. 2).

This model (Fig. 1, Tab. 2) can be used for loss estimations on the micro-scale, i.e. on a building-by-building basis. While water level, building type and building quality are always taken into account, precaution and contamination should only be considered, if appropriate information is available.

Tab. 1: Factors that are considered in the Flood Loss Estimation MOdels for the private sector (FLEMOps).

Factor	Classification
Water level	<21 cm, 21-60 cm, 61-100 cm, 101-150 cm, >150 cm
Building type	One-family homes, (semi-)detached houses, multifamily houses
Building quality	Low/medium quality, high quality
Contamination of the flood water	None, medium, heavy (i.e. oil or multiple) contamination
Private precaution	None, good, very good precaution

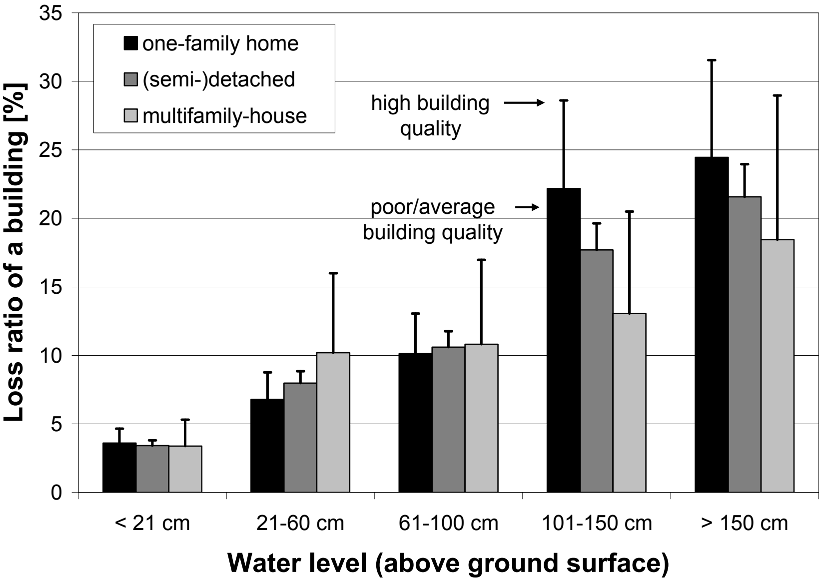

Fig. 1: Micro-scale FLEMOps model for the estimation of flood losses to residential buildings considering water level, building type and building quality; derived from data of 1697 households affected by the August 2002 flood (adapted from Büchele et al., 2006).

Tab. 2: Scaling factors for building losses in the private and commercial sector due to private precautionary measures and the contamination of the floodwater (adapted from Büchele et al., 2006).

	Code	Loss at residential buildings	Loss at household contents
No contamination, no precaution	C0P0	0.92	0.90
No contamination, good precaution	C0P1	0.64	0.85
No contamination, very good precaution	C0P2	0.41	0.64
Medium contamination, no precaution	C1P0	1.20	1.11
Medium contamination, good precaution	C1P1	0.86	0.99
Medium cont., very good precaution	C1P2	0.71	0.73
Heavy contamination, no precaution	C2P0	1.58	1.44

Tab. 3: Typical composition of building types derived from [10] (data are given in percentage of building type per cluster, OFH: one-family home, SDH: (semi-)detached house, MFH: multifamily house).

Cluster	Share OFH (%)	Share SDH (%)	Share MFH (%)	Description
1	12.00	5.13	82.87	Dominated by multifamily houses
2	31.35	24.58	44.07	Mixed (high share of MFH)
3	37.51	46.19	16.30	Mixed (high share of SDH)
4	68.51	21.43	10.05	Mixed (high share of OFH)
5	92.25	4.81	2.94	Dominated by one-family homes
all	73.20	14.30	12.50	Mean composition

2.3 Scaling loss functions for applications on the meso-scale

For loss estimations on large areas building-oriented loss functions are often not feasible. Furthermore, required input data, especially official cadastral data with exact locations and extents of the buildings, are not available on a regional or countrywide scale in Germany. For usage on the meso-scale, i.e. an application of loss functions to (homogeneous) land use units, micro-scale loss models have thus to be adapted.

Two scale mismatches have to be overcome by a meso-scale model. First, there is a scale mismatch between the empirical data, which were used to derive the loss functions, (building level) and the scale of model application (land use units). In FLEMOps this mismatch is overcome by the use of census data. Such data are provided by INFAS Geodaten GmbH (2001) and contain information about the absolute and relative numbers of different building types and their quality per postal zone or per municipality covering the whole of Germany.

For loss modelling, the INFAS-building types were first mapped onto the three building types used in the loss model (see Fig. 1). The share of each building type was calculated per postal zone as well as per municipality. The building types of the postal zones were classified by means of a cluster analysis in SPSS (k-means algorithm with Euclidean distance). The 5-cluster solution revealed a reasonable classification (see Tab. 3) and was further used to classify all municipalities, as well. Further, a mean building quality per municipality was calculated from the information about the building quality in INFAS Geodaten (i.e. value of the equipment, windows, doors etc.), which is distinguished in six classes (from 1 “exclusive building quality” to 6 “very poor quality”).

With the help of these municipal classifications, a mean loss function is set up: The micro-scale model shown in Fig. 1 for each of the three building types is weighted by the mean percentages of the building types in the cluster that was assigned to the municipality under study (see Tab. 3) considering the mean building quality in the municipality at hand. In fact, only ten different loss model variations result.

Secondly, there is a scale mismatch between hazard and exposure data. While hazard estimates are commonly modelled as a detailed grid, exposure data such as asset values are commonly only available at coarse units such as municipalities. Therefore, asset data have to be disaggregated within the municipality at hand. In a first rough, but countrywide approach, this scale mismatch was closed by disaggregating municipal asset data on the basis of CORINE land cover data (CLC2000) with the help of a dasymetric mapping approach developed by (Gallego, 2001). The adaptation of this method for loss modelling was demonstrated by Thieken et al. (2006a).

Loss calculation on the meso-scale is done on a raster level using tools in ArcView and Matlab. For each grid cell, the loss ratio is determined by the inundation depth in that cell and the underlying municipality that is connected to a typical composition of building types (cluster) and a mean building quality. Then, the loss ratio is multiplied by the asset value assigned to each grid cell. This procedure allows a countrywide application of the model FLEMOps. Due to the roughness of the method, meso-scale loss estimates are finally summarised per municipality and adjusted using the scaling factors listed in Tab. 2.

3 MODEL APPLICATION AND EVALUATION

For an application of FLEMOps two kind of input information is needed: Inundation depths and asset data – either on the micro-scale, i.e. appropriate information is needed at all affected buildings or on the meso-scale, i.e. spatial information about the inundation depths and an (aggregated) asset portfolio on the municipal level is necessary. For a model evaluation an additional independent data set with loss information, e.g. repair costs at single affected buildings or of a whole municipality is essential. The term "independent data set" implies that the loss data have not already been used for model derivation outlined in section 2.

3.1 Micro-scale model validation

On the micro-scale, the model FLEMOps+ was used to estimate losses of single buildings affected by the August 2002.

Input Data In three affected municipalities in Saxony, records of eligible repair costs, which almost represent the building loss, were provided by the Saxon Relief Bank (Sächsische Aufbaubank – SAB) and were combined with information about building types and observed and/or simulated water depths at the buildings by Kobsch (2005). The mean asset value per building type and municipality was taken from the work of Kleist et al. (2006), the level of contamination and precaution was derived from the telephone interviews described in section 2.1.

Results and discussion The total and mean building loss estimates in the three municipalities are summarised in Tab. 4. Besides the observed water levels, different simulated water levels were used. To get an idea which estimate should be rejected and which could be accepted, a resampling method (bootstrap) was performed with all loss records per municipality so that a confidence interval of the total and the mean building loss could be constructed. Loss estimates that fall within the 95% interval of the resampled data were assumed to be acceptable. Tab. 4 shows that FLEMOps+ performs well with observed water levels, but fails in some cases with simulated water levels.

Tab. 4: Building loss estimates on the micro-scale in three municipalities affected by flooding in August 2002.

	Total damage [Mill. Euro]	Mean building damage [Euro]	Model evaluation
Municipality of Döbeln (n = 379; CV = 131%)			
SAB – eligible costs	45.71	120610	
95% bootstrap interval of SAB-data	40.24…52.28	106260 … 137940	
FLEMOps+ with observed water levels	42.86	113090	+
FLEMOps+ with simulated water levels (1D-Model, see [13])	39.46	104119	-
FLEMOps+, with simulated water levels (LISFLOOD-FP, provided by GFZ Potsdam)	40.99	108143	+
Municipality of Eilenburg (n = 550; CV = 115%)			
SAB – eligible costs	54.46	99023	
95% bootstrap interval of SAB-data	49.97…60.61	90979 … 109700	
FLEMOps+ with interpolated water level observations	55.40	100728	+
FLEMOps+ with simulated water levels (LISFLOOD-FP provided by GFZ Potsdam)	45.34	82431	-
Municipality of Grimma (n = 345; CV = 82%)			
SAB – eligible costs	44.45	128830	
95% bootstrap interval of SAB-data	40.75…48.43	117850 ... 140360	
FLEMOps+ with observed water levels	48.48	140519	(+)
FLEMOps+, with simulated water levels (2D-Model, provided by the Saxon Dam Authority)	47.75	138393	+

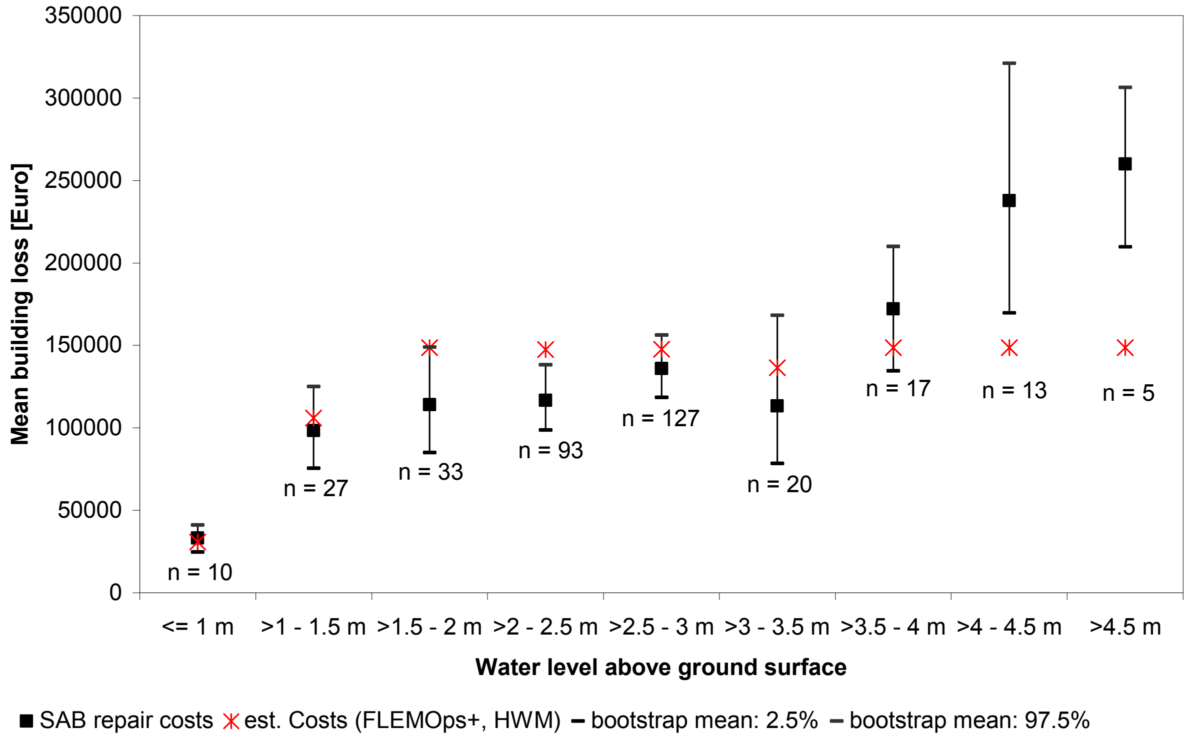

Fig. 2: Performance of the model FLEMOps+ in different water level classes using 345 loss records from the municipality of Grimma.

To get an idea about the weaknesses of the model, model performance was analysed in different classes of water levels and flow velocities. Fig. 2 shows exemplarily that the model fails to correctly estimate the building loss at very high water levels that occur in case the first floor is also flooded. Therefore, a further water level class reflecting very high inundation should be introduced.

3.2 Meso-scale model validation

On the meso-scale, loss estimates of whole municipalities are calculated. FLEMOps+ was applied to five Saxon municipalities that were affected by the flood in August 2002 as well as to five municipalities in Baden-Wuerttemberg that experienced flooding in December 1993. Besides, a comparison with three simple stage-damage functions was performed. In the first model, loss to residential buildings is calculated by the function $y = (2x^2 + 2x)/100$, where y is the loss ratio and x is the water level given in meter (ICPR, 2001). In the second model, the loss ratio results from a linear function $y = 0.02x$ where y is the loss ratio and x the water level given in meter (MURL, 2000a). For water levels of more than 5 m the loss ratio is set to 10 %. For some flood action plans, a third kind of stage-damage-function has been used in Germany: $y = (27 \sqrt{x})/100$, where y is the loss ratio and x is the water level given in meter (Hydrotec, 2001).

Input Data The August 2002 flood event was simulated by the 1D/2D-model LISFLOOD-FP (Bates and de Roo, 2000) in the municipalities Döbeln and Eilenburg. In another three municipalities the inundation depths were derived by intersecting the inundation line of August 2002 flood with a Digital Elevation Model as outlined in the work of Grabbert (2006). In order to also apply FLEMOps+, the classification for contamination and precaution was derived from the survey data introduced in section 2.1. Loss data for 2002 were again provided by SAB and contained the sum of eligible repair costs per municipality as at February 2005. Since the number of reported loss records per municipality exceeds the number of interviews at least ten times, the data sets can be regarded as independent.

For the municipalities affected by flooding in 1993, loss data were provided by the affected municipalities and the local building insurer. The inundation scenarios were provided by the Seckach-Kirnau-project.

As further input, the map of disaggregated residential asset values as provided by Thieken et al. (2006a) was used in all meso-scale applications. The assets were adapted to the years 1993 and 2002 by the respective price indices for construction which are continuously published by the Federal Statistical Agency.

Results and discussion The loss estimates per municipality and loss model are shown in Fig. 3. Losses for 2002 flood event were best estimated by FLEMOps and FLEMOps+, while the stage-damage-functions tend to underestimate in case of MURL-Model and ICPR-Model or to overestimate in case of the Hydrotec-Model. However, model performance is much lower in case of the 1993 flood event (Fig. 3). While the mean relative error of the estimates for the 2002 event amount to 24% for FLEMOps+, it is more than 1000 % in case of the 1993 flood (see Olschewski, 2007, for further details). Therefore, the regional validity of loss models has to be investigated further.

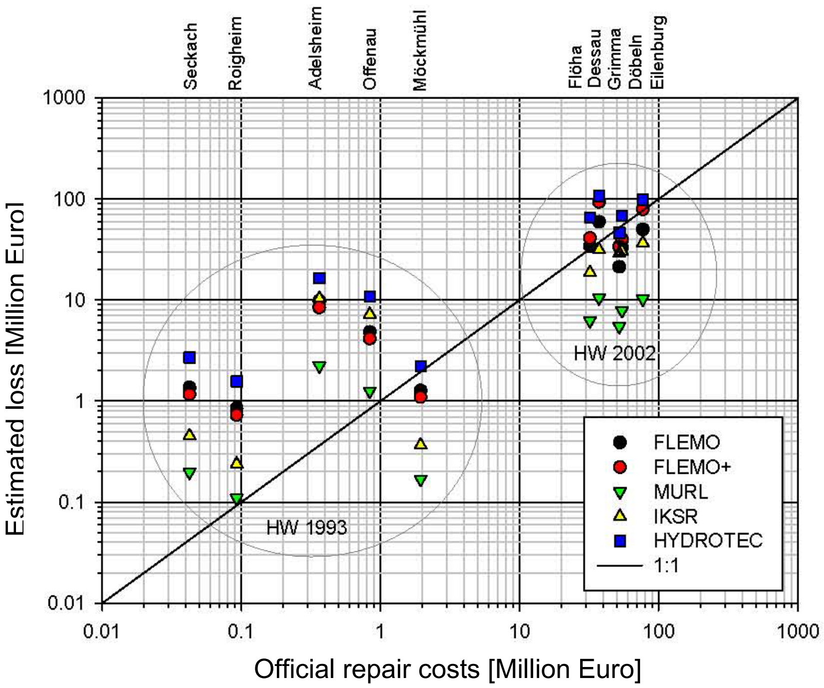

Fig. 3: Official repair costs and estimated building losses in ten municipalities that were affected by flooding in 1993 (HW1993) or in 2002 (HW2002).

4 SUMMARY AND CONCLUSIONS

In the aftermath of a severe flood event in August 2002 in Germany 1697 flood affected private households were interviewed. Besides the losses to buildings and contents a variety of factors that might influence the flood loss were analysed. From the surveyed data, the new Flood Loss Estimation Model for the private sector FLEMOps+ was derived. In comparison to existing loss models, the new model covers more influencing factors such as precaution or contamination. First model evaluations on the micro- and the meso-scale confirm that the new model is better capable of estimating flood losses, except for losses caused by very high water levels. Moreover, the error in loss modelling seems to be high and transferability of loss models to other regions seems to be limited. Further, it has to be questioned whether loss models that were derived from data of an extreme flood such as the 2002 event can be applied to more frequent floods. Therefore, additional model evaluations are needed.

References can be found at the end of the thesis.

Paper 8: Urban flood risk assessment – How detailed do we need to be?

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Abstract

Applied flood risk assessments, especially in urban areas, very often pose the question how detailed the analysis needs to be in order to give a realistic figure of the expected risk. The methods used in research and practical applications range from very basic approaches with numerous simplifying assumptions up to very sophisticated, data and calculation time demanding applications both on the hazard and vulnerability part of the risk. In order to shed some light on the question of required model complexity in flood risk analyses and outputs sufficiently fulfilling the task at hand, a number of combinations of models of different complexity both on the hazard and vulnerability side were tested in a case study. The different models can be organised in a model matrix of different complexity levels: On the hazard side the approaches/models selected were A) linear interpolation of gauge water levels and intersection with a digital elevation model (DEM), B) a mixed 1D/2D hydraulic model with simplifying assumptions (LISFLOOD-FP) and C) a full 2D hyperbolic hydraulic model considering the built environment and infrastructure. On the vulnerability side the models used for the estimation of direct damage to residential buildings are in order of increasing complexity: I) meso-scale stage-damage functions applied to CORINE land cover data, II) the rule-based meso-scale model FLEMOps+ using census data on the municipal building stock and CORINE land cover data and III) a rule-based micro-scale model applied to a detailed building inventory. Besides the inundation depths, the latter two models consider different building types and qualities as well as the level of private precaution and contamination of the floodwater. The models were applied in a municipality in southeast Germany, Eilenburg. It suffered extraordinary damage during the flood of August 2002, which was well documented as were the inundation extent and depths. The analysis shows that the combination of the 1D/2D-model and the meso-scale damage model FLEMOps+ performed best and provide a good compromise between data requirements, simulation effort, and an acceptable accuracy of the results. The more detailed approaches suffered from complex model setup, high data requirements, and long computation times.

Keywords: flood risk, hydraulic modelling, damage estimation, prediction uncertainty, model performance

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1 INTRODUCTION

Risk-oriented methods and risk analyses are gaining more and more attention in the fields of flood design and flood risk management since they allow us to evaluate the cost-effectiveness of prevention measures and thus to optimise investments (e.g. Resendiz-Carrillo and Lave 1990; USACE 1996; Olsen et al. 1998; Al-Futaisi and Stedinger 1999; Ganoulis 2003). Moreover, risk analyses quantify the risks and thus enable (re-)insurance companies, municipalities and residents to prepare for disasters (e.g. Takeuchi 2001; Merz and Thieken 2004).

The Flood Directive of the European Commission (EU 2007) will require flood risk maps for all river basins and sub-basins with significant potential risk of flooding in Europe. The most common approach to define flood risk is the definition of risk as the product of hazard, i.e. the physical and statistical aspects of the actual flooding (e.g. return period of the flood, extent and depth of inundation), and the vulnerability, i.e. the exposure of people and assets to floods and the susceptibility of the elements at risk to suffer from flood damage (e.g. Mileti 1999; Merz and Thieken 2004). This definition is adopted in the Flood Directive (EU 2007). Following this definition, meteorological, hydrological and hydraulic investigations to define the hazard and the estimation of flood impact to define vulnerability can be undertaken separately in the first place, but have to be combined for the final risk analysis.

Clearly, risk quantification depends on spatial specifications (e.g., area of interest, spatial resolution of data) and relies on an appropriate scale of the flood hazard and land use maps. For instance, for planning and cost-benefit analysis of flood-protection measures and for the preparedness and prevention strategies of individual stakeholders (communities, companies, house owners etc.), very detailed spatial information on flood risk is necessary. For both the hazard and vulnerability assessment a number of approaches and models of different complexity are available and many of them were used in scientific as well as applied flood risk assessments and on different scales. Examples of flood risk analyses are available on municipal level (Baddiley 2003; Grünthal et al. 2006), catchment level (MURL 2000a; ICPR 2001; Dutta et al. 2003; Dutta et al. 2006), on a national scale (Hall et al. 2003; Rodda 2005) and European level (Schmidt-Thomé et al. 2006).

Hazard assessments give an estimation of the extent and intensity of flood scenarios and associate an occurrence probability to it (Merz and Thieken 2004). The usual procedure is to apply a flood frequency analysis to a given record of discharge data (e.g. Stedinger et al. 1993) and to transform the discharge associated to defined return periods, e.g. the 100 year event into inundation extent and depths. Examples for the resulting flood hazard maps can be found in the references cited in the previous paragraph for all spatial scales. This apparently simple approach has a number of pitfalls and uncertainties, which need to be considered. These uncertainties stem e.g. from the inappropriateness of the extreme value function for the given data series, violation of the underlying assumptions of the extreme value statistics, i.e. stationarity and homogeneity of the data series, and shortness of the data series and large uncertainties in the extrapolation range (e.g. Apel et al. 2008). But also the hydraulic transformation has a number of methodological problems, which are usually associated with the selection of the appropriate model, the consideration of dikes and even more dike breaches and the calibration and validation of the models. Depending on the scale of the hazard, resp. risk assessment the complexity of models applied range from simple interpolation methods to sophisticated and spatially detailed models solving the shallow water equations in two dimensions. However, the correctness of the models can usually be qualitatively guessed only, because sufficient data on inundation extent and depths for the calibration and validation of the models is lacking. Therefore the question of how detailed a model should be in order to give reasonable results is often answered pragmatically given the available resources and data and is not based on quantitative goodness of fit estimates. In the presented study this problem is explicitly addressed because an extensive data set on inundation extent and depths could be collected during and after the large flood of the Elbe and its tributaries in August 2002 in Germany.

Moreover, Pappenberger et al. (2007) pointed out that traditional model performance measures might be inadequate for flood hazard/risk studies. They therefore introduced a vulnerability-weighted performance measure for model selection. In the present study a different approach is chosen, but also includes vulnerability assessments.

Vulnerability assessments are normally restricted to the estimation of detrimental effects caused by the floodwater. Frequently, vulnerability analyses focus only on direct flood damage which is estimated by damage or loss functions. Most damage models have in common that the direct monetary damage is a function of the type or use of the building and the inundation depth (Smith 1981; Krzysztofowicz and Davis 1983; Wind et al. 1999; NRC 2000; Green 2003). This concept is supported by the observation of Grigg and Helweg (1975) "that houses of one type had similar depth-damage curves regardless of actual value". Such depth-damage functions are seen as the essential building blocks upon which flood damage assessments are based and they are internationally accepted as the standard approach to assessing urban flood damage (Smith 1994). Usually, building-specific damage functions are developed by collecting damage data in the aftermath of a flood. Another data source are "what-if analyses" by which the damage which is expected in case of a certain flood situation is estimated, e.g. "Which damage would you expect if the water depth was 2m above the building floor?". On the base of such actual and synthetic data generalised relationships between damage and flood characteristics have been derived for different regions. Green (2003) provides stage-damage curves for different building types and uses in various countries, e.g. UK, USA, Japan. Probably the most comprehensive approach has been the "Multi-Coloured Manual" and its precursors that contain stage-damage curves for - among others - 28 typical dwelling types in the UK (Penning-Rowsell and Chatterton 1977; Penning-Rowsell et al. 2005).

Recent studies have shown that estimations based on stage-damage functions may have a large uncertainty since water depth and building use only explain a part of the data variance (Merz et al. 2004). It is obvious that flood damage depends, in addition to building type and water depth, on many factors, e.g. on flow velocity, duration of inundation, availability and information content of flood warning, precaution and the quality of external response in a flood situation (Smith 1994; Wind et al. 1999; Penning-Rowsell and Green 2000; IKSR 2002; Kreibich et al. 2005a). Some damage models include parameters like flood duration, contamination, early warning or precautionary measures (Penning-Rowsell et al. 2005; Büchele et al. 2006; Thieken et al. 2008). While the outcome of most of the functions is the absolute monetary loss of a building, some approaches provide relative loss functions, i.e. the loss is given in percentage of the building or content value (e.g. Dutta et al. 2003; Thieken et al. 2008), or as index values, e.g. loss may be expressed as an equivalent to the number of median-sized family houses totally destroyed (Blong 2003). If these functions are used to estimate the loss due to a given flood scenario property values have to be predetermined.

As outlined by Messner and Meyer (2005) flood loss estimation can be performed on different scales: In small investigation areas with detailed information about type and use of single buildings micro-scale analyses can be undertaken. Here, flood loss is evaluated on an object level, e.g. at single buildings. For bigger areas a meso-scale approach is advantageous. These approaches are based on aggregated land cover categories, which are connected to particular economic sectors. Loss is then estimated by aggregated sectoral models (Messner and Meyer 2005).

However, despite the large number of flood risk analyses there is still no study present that investigates the performance of different approaches and models compared to an actual flood event. The reason for this is the scarcity of valuable calibration and validation data, for both, hazard and vulnerability models. For a thorough calibration and validation of any flood risk analysis numerous data sets are necessary. For the hazard side, which is usually covered by a hydraulic model, this would ideally be

- up- and downstream flow hydrographs,
- mapped inundation extents,
- recorded inundation depths, especially in urban areas, and
- flow velocities in case of fast flowing rivers (flash flood areas).

For the vulnerability side the data demands depend on the type of damage considered and the chosen modelling approach. In this paper, damage estimation is restricted to direct monetary damage at residential buildings. Different model approaches at the meso- as well as at the micro-scale are applied. Basically the following data sets are required:

- hazard data of the event: inundation extent and depths,
- exposure data: building inventory, especially the location of buildings, or land cover data; types and asset values of buildings,
- susceptibility data: building characteristics, and further data sets depending on the damage model,
- damage data: total amount of damage due to the flood event under study, e.g. the sum of all residential building repair costs.

Comprehensive calibration and validation data sets like these are hardly available. Damage data are rarely gathered, (initial) repair cost estimates are uncertain and data are not updated systematically (Dowton and Pielke 2005). Let alone the problem of obtaining quality elevation and river morphology data. Hence the question of performance of different flood risk assessment approaches could not be investigated until now. However, during and after the extreme flood in the catchments of the rivers Elbe and Danube in August 2002 that caused a total damage of 11830 million Euro in Germany (Munich Re, 2007), quite a large number of data could be collected. Therefore, the lists above could be almost completed in some parts of the affected area. In this paper, a comparative study with three different types of hydraulic and damage models will be undertaken using the municipality Eilenburg at the river Mulde in Saxony, Germany, as an example. Based on the performance of different model combinations, which were evaluated with the collected flood and damage data, a recommendation of a combination of hazard and damage model is given, representing the best compromise between accuracy and modelling effort.

2 MODEL DESCRIPTIONS

For the comparative study we selected models of three different complexity levels for both the hazard and damage analysis. Each hazard model was combined with each damage model. This resulted in a model combination matrix shown in Figure 1.

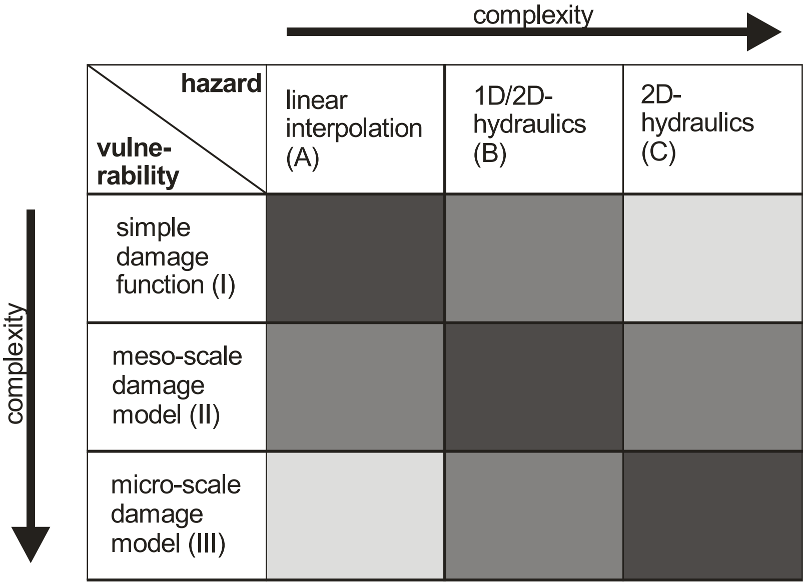

Fig. 1: The comparative model matrix. Dark colours represent match in complexity, light colours a mismatch.

The damage estimates of all combinations were finally compared to official damage data in order to evaluate the overall model performance. Since the official damage data consisted of 765 single records a resampling algorithm (bootstrap, Efron, 1979) could be applied to derive a frequency distribution of the total damage sum. Loss estimates that fall within the 95% interval of the resampled loss data were assumed to be acceptable. Other combinations were rejected.

The hazard models selected were in order of ascending complexity: A) linear interpolation of gauge levels and intersection with a DEM, B) a hybrid 1D/2D hydraulic model and C) a full 2D hyperbolic hydraulic model. For comparison we also included a data driven approach to derive the water levels by intersecting a water mask of an observed flood event with the DEM. While this approach doesn’t allow any extrapolation to other events, it can be taken as a benchmark for the evaluation of quality of the model results.

For the damage estimation I) meso-scale stage-damage functions, II) a rule-based meso-scale model and III) a rule-based micro-scale damage model were chosen. The damage assessment was restricted to direct losses at residential buildings.

The following paragraphs give a brief description of the models:

2.1 Hazard model A: Linear Interpolation

Linear interpolation is the simplest way to reconstruct floodplain inundation from measured gauge levels: Water levels at gauging stations, either measured during an event or synthetically derived, are linearly interpolated for any point of the reach between the gauges and hence a uniform sloping flood level is created. This level is intersected with a DEM. All areas below the interpolated flood levels are indicated as inundated and the inundation water level is the difference between the terrain elevation and the flood level. For this study, modelling results from the work of Grabbert (2006) were used.

The method is very simple and thus suffers from a number of drawbacks. For example, there is no volume control of the floodplain inundation, which results in huge and unrealistic flooded areas especially in unbounded lowlands. Moreover, the effects of dike lines are often neglected, because they are normally not or hardly represented in the DEM. Further, the actual dynamics of the inundation process are completely neglected.

A similar cut and fill procedure was performed for the benchmark scenario. Here, the water mask of a flood event derived from satellite data was intersected with the DEM. By this approach the disadvantages of the linear interpolation are avoided and the derived inundation depths can be regarded as the best spatially distributed representation of the maximum inundation depths of the observed flood event.

2.2 Hazard model B: 1D/2D-model

In this approach the hydrodynamics are represented one-dimensionally in the actual stream, whereas the floodplain inundation is modelled spatially explicit in a two-dimensional fashion. In this study, the model LISFLOOD-FP (Bates and De Roo, 2000) was used. In this model the river channel is simplified by a rectangular channel and for the hydrodynamics the kinematic wave model is used. The 2D-part is a storage cell model based on the DEM with spatial explicit flows in x- and y-directions, which are calculated with an approach identical to the diffusion wave simplification of the full St.-Venant equations (Chow et al. 1988). This model needs a basic data set regarding the channel presentation (a number of cross section definition consisting of coordinates, bed elevation, channel width and roughness coefficient), a DEM and spatial explicit roughness coefficients for the floodplain inundation. These data sets are comparatively easy to obtain and an initial model setup can be done within a short time with the help of a DEM, land cover maps that are used for the roughness coefficient estimation and topographical maps for basic channel data. However, while being sufficiently exact in natural flow conditions on floodplains, the model is not able to represent the flow conditions in a built environment correctly, because the obstructions caused by the buildings are not explicitly taken into account..

2.3 Hazard model C: full 2D-model

In order to model the flow regime in an urban area a more detailed, full two-dimensional model has to be used, which is able to consider the hydraulically important features like streets, buildings, channels etc. In this study we applied the model of Aronica et al. (1998). This model is based on the St.-Venant equations for two-dimensional shallow-water flow, with convective inertial terms neglected in order to eliminate the related numerical instabilities. The St.-Venant equations are solved using a finite element technique with triangular elements. The finite element approach proposed allows to avoid a simplified description of the hydraulic behaviour of flooded areas due to the fact that triangular elements are capable of reproducing the detailed complex topography of the built-up areas, i.e. blocks, street networks, etc. exactly as they appear within the floodable area with an appropriately constructed mesh (Aronica and Lanza 2005). Blocks and other obstacles are treated as internal islands within the triangular mesh covering the entire flow domains.

This model needs a basic data set regarding the floodplain topography (topographical map with a scale of 1:10000 and lower), a high spatial resolution DEM (in comparison with the spatial resolution of the finite element discretisation) and spatially explicit roughness coefficients for the floodplain inundation. In addition, a data set about the river topography, i.e. a number of cross section definitions with bed elevations, channel widths and roughness coefficients, can be useful to improve the mesh descriptive capability in those parts of floodplains (Horritt and Bates 2001).

2.4 Vulnerability model type I: meso-scale stage-damage functions

In this study, three different types of stage-damage functions are used, which have been applied in flood action plans or risk mapping projects in Germany. All models are suitable for applications on the meso-scale, i.e. for the application to land cover units.

In the MURL-Model (MURL 2000a), the damage ratio to buildings is given by a linear function $D = 0.02h$ where D is the damage ratio and h the water level given in meter. For water levels of more than 5 m the damage ratio is set to 10 %.

In the ICPR-Model (ICPR 2001), damage at residential buildings is estimated by the relation $D = (2h^2 + 2h)/100$, where D is the damage ratio and h is the water level given in meter.

For some flood action plans, a third function was used: $D = (27\sqrt{h})/100$, where D is the damage ratio and h is the water level given in meter (HYDROTEC 2001; HYDROTEC 2002).

First, these functions are applied to an inundation scenario in order to estimate the damage ratio per grid cell. These ratios are then each multiplied by the specific asset value assigned to the corresponding grid cell. The total asset value of residential buildings was taken from the work of Kleist et al. (2006). Since only the total asset sum is provided for each municipality, the assets are disaggregated on the basis of the CORINE land cover data 2000 (CLC2000) and a dasymetric mapping approach based on Mennis (2003).

2.5 Vulnerability model type II: the meso-scale Flood Loss Estimation MOdel for the private sector (FLEMOps)

To account for more damage-influencing factors, the rule-based Flood Loss Estimation MOdel for the private sector FLEMOps has been developed. The model is based on a survey of 1697 private households that were affected by the flood in August 2002 (Kreibich et al. 2005a; Thieken et al. 2005). The model calculates the damage ratio at buildings for five classes of inundation depths, three distinct building types and two categories of building quality. In an additional modelling step (further FLEMOps+), also the influence of the contamination of the floodwater and precaution of private households can be considered by scaling factors (see Büchele et al. 2006). The model can be applied to the micro-scale, i.e. to single buildings (vulnerability model type III) as well as to the meso-scale, i.e. to land cover units. For the latter, a scaling procedure based on census data and a dasymetric mapping technique was developed (Thieken et al. 2006a): By means of INFAS Geodaten (2001) and cluster analysis the mean building composition and the mean building quality per municipality was derived for whole Germany. With the help of this classification, a mean damage model was set up by weighting the damage model for three different building types by the mean percentages of these building types in each cluster. For example: The mean composition of residential buildings in the municipality of Eilenburg is represented by cluster 2, i.e. 31 % of the houses are one-family homes, 25 % are (semi-)detached houses and 44 % are multifamily houses.

According to the INFAS data, the mean building quality in Eilenburg is slightly below average. Thus, the mean damage ratios DR_{mean} for Eilenburg are calculated with:

$$DR_{mean} = 0.31 * DR_{OFH} + 0.25 * DR_{SDH} + 0.44 * DR_{MFH}$$

where: DR_{OFH}: damage ratio for one-family homes and poor/average building quality,
DR_{SDH}: damage ratio for semi-detached houses and poor/average building quality,
DR_{MFH}: damage ratio for multifamily houses and poor/average building quality.

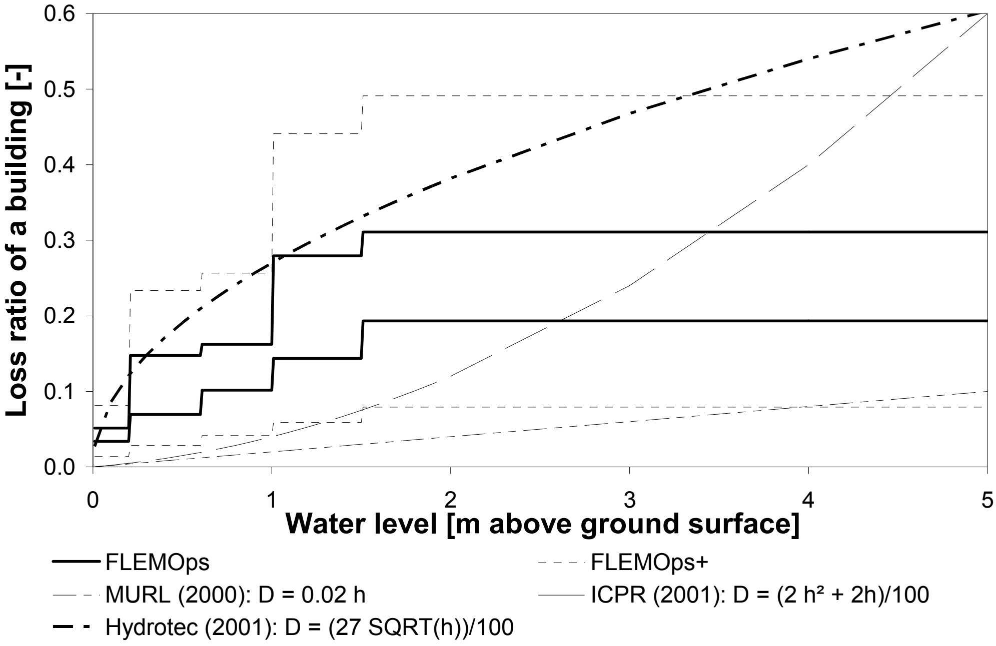

Fig. 2: Different meso-scale stage-damage functions and the meso-scale damage model FLEMOps adapted to the municipality of Eilenburg.

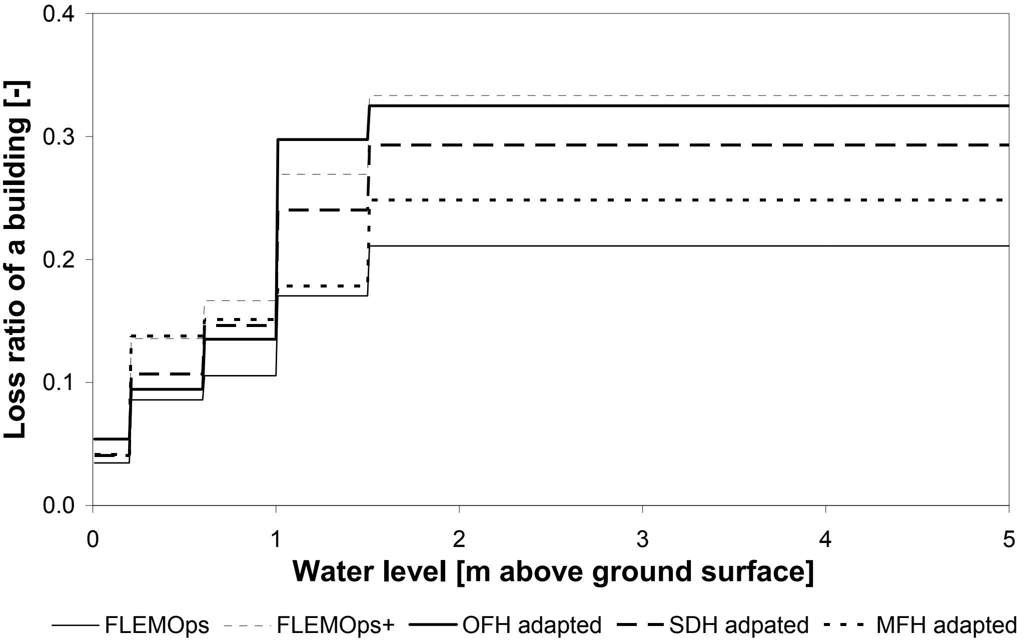

Fig. 3: The meso-scale and micro-scale damage function of the model FLEMOps+ adapated to the municipality of Eilenburg (OFH: one-family home, SDH: (semi-)detached house, MFH: multifamily house).

The resulting model is shown in Fig. 2. For the second model stage (FLEMOps+) a scaling factor of 1.58 for heavy contamination and no precaution was used (see Tab. 1). Fig. 2 demonstrates that FLEMOps adapted to Eilenburg is theoretically within the range of the three stage-damage functions mentioned before. However, the advantage is that it takes into account the building characteristics of the area under investigation.

2.6 Vulnerability model type III: damage estimation on the micro-scale

On the micro-scale the model FLEMOps was applied in two variants: First, the mean damage function that was used on the meso-scale (Fig. 2) was applied to single buildings. Affected buildings were determined by means of the official land register. For the damage calculation, a mean property value was assigned to each affected building (Tab. 1).

In the second approach, building-type-specific damage models were used together with a mean property value per building type. The damage estimate was corrected considering the share of buildings with high and average quality and the share of different levels of precaution and contamination in the municipality under study. The resulting functions are shown in Fig. 3. For this approach, a distinct building type had to be assigned to each building in the land register. This step is particularly prone to uncertainty since the only information available is a rough classification of the building use: residential use on the one hand and commercial, industrial or other uses on the other hand. Many buildings in Eilenburg were attributed to the second category. However, a lot of these buildings in the town centre are actually used for both residential and commercial purposes and were thus included in the damage estimation. Further, no information was available about the building types. Thus, types had to be assigned on the basis of the building area and geometry.

3 CASE STUDY

For the comparative study we selected the municipality of Eilenburg in Saxony, Germany. It suffered enormous damage in August 2002, when the Mulde river, a tributary of the Elbe, flooded the whole city with inundation depths up to 5 m in the vicinity of the river and 3 m in the town. An important hydraulic feature is the Mühlgraben, a bypass of the Mulde river (Fig. 4), which is diverted from the main stream approx. 10 km upstream of Eilenburg and conveys water through the western part of the city. It rejoins the Mulde within the municipal boundary of Eilenburg. In August 2002, this caused a flooding of the old city from two sides, thus aggravating the already worse flooding condition. Fig. 4 shows the topographical map of the city and surroundings.

Because of its enormous extent, the flooding was well documented, as was the damage. A shapefile indicating the maximum inundation extent was surveyed from satellite imaging and water marks (Fig. 5). Flood depths were recorded from water marks at 400 buildings in the city centre thus yielding detailed point information of inundation depths in the town and were provided by Schwarz et al. (2005 pers. comm.). These extensive data could be used for the calibration of the inundation models. Upstream boundary conditions were given by the measured hydrograph at the gauge Golzern, which is the closest gauging station. However, the next and last downstream gauging station of the Mulde was destroyed during the flood and consequently the downstream boundary could not be used for model calibration.

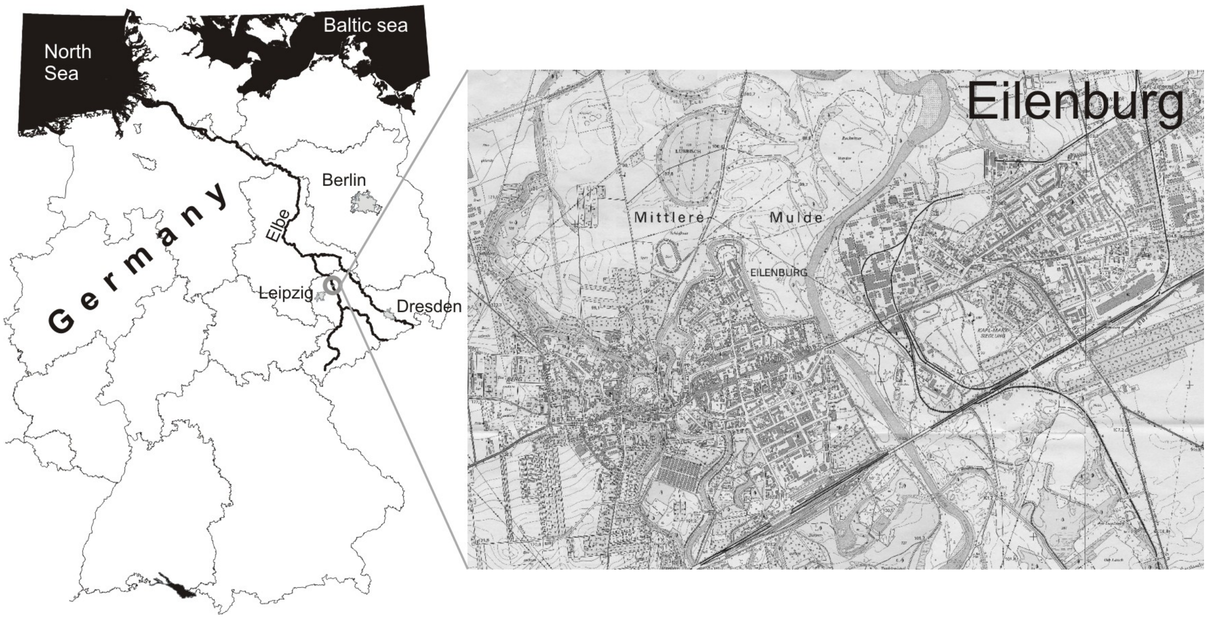

Fig. 4: Investigation area overview and topographical map of Eilenburg.

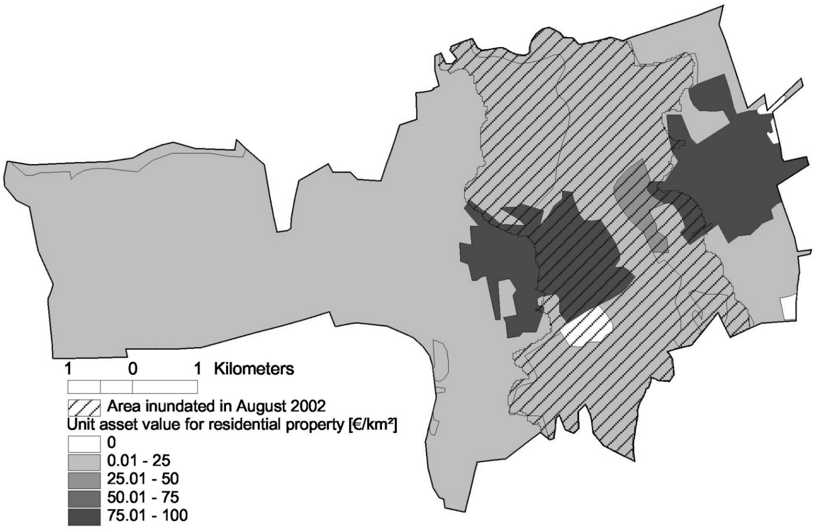

Fig. 5: Unit-specific asset value of residential buildings for the meso-scale damage models type I and II (based on data of Kleist et al. (2006) and dasymetric mapping algorithm adapted from Mennis (2003) and the extent of the inundation area in August 2002 in Eilenburg (data source: UFZ Halle-Leipzig, 2003, pers. comm.).

The total damage is also well documented by the Saxon Relief Bank (SAB) because a huge damage compensation program was released after the flood. The SAB kept track of the repair works and costs as declared by the property owners and their reconstruction aid. According to the damage compensation guidelines (SMI 2002), costs for repairing or replacing damaged household contents and/or damaged outside facilities (fences, plants etc.) were excluded from the compensation. Therefore, the eligible repair costs almost represent the total building damage. In Eilenburg, the sum of the eligible costs amounted to € 77.12 million consisting of 765 records with a minimum 4198 € and a maximum of 2,365,722 € (Tab. 1). This leaves us with a comparatively accurate estimation of the monetary building damage in the town, against which the different risk assessment model combinations could be tested. In Tab. 1 and Fig. 5 also other input data necessary for the damage models are summarised. Private precaution was negligible in Eilenburg before the flood in 2002 and additionally the floodwater was contaminated by oil in more than 50% of the cases of affected households (Tab. 1).

Tab. 1: Input data for the damage assessment in the municipality of Eilenburg (Saxony, Germany) for the flood event in August 2002.

Building characteristics and asset information	
Number of residential buildings according to INFAS Geodaten	3505
Share of buildings with high or exclusive quality according to INFAS Geodaten	7 %
Share of buildings with average or low quality according to INFAS Geodaten	93 %
Total assets of residential buildings in the municipality of Eilenburg (Kleist et al., 2006)	€ 771 million
Mean asset value for residential buildings	220060 €
Mean asset value for one-family homes	104324 €
Mean asset value for (semi-)detached houses	92506 €
Mean asset value for multifamily and apartment houses	539562 €
Telephone survey after the flood event in August 2002 (Kreibich et al., 2005a; Thieken et al., 2005)	
Number of surveyed households in Eilenburg	37
Share of households not affected by contaminated floodwater	24.3 %
Share of households affected by heavily contaminated floodwater (oil contamination)	64.9 %
Share of households that performed NO precautionary measures	89.1 %
Share of households that performed ONE precautionary measure	5.4 %
Share of households that performed MORE THAN ONE precautionary measure	5.4 %
Information of the Saxon Relief Bank (Sächsische Aufbaubank - SAB, as at 17 February 2005)	
Total eligible repair costs for damage to residential buildings in August 2002	€ 77.12 million
Number of buildings to be repaired	765

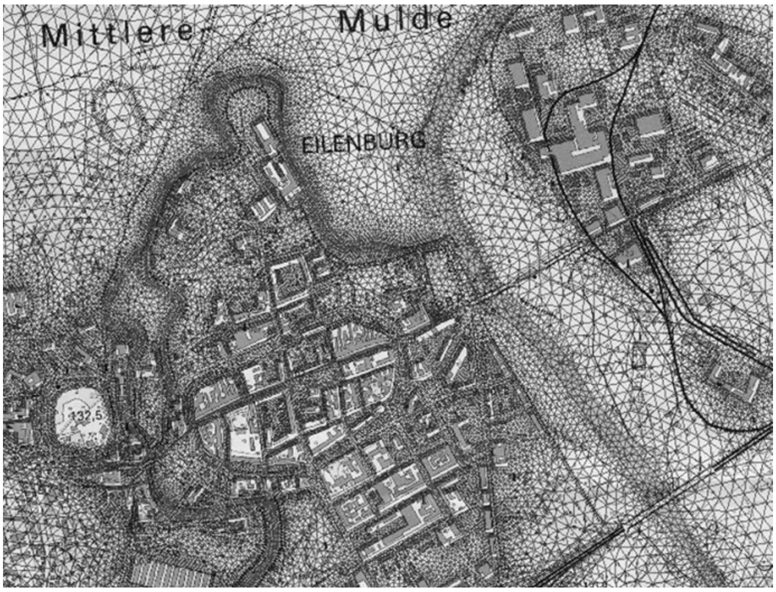

Fig. 6: Layout of the mesh of the full 2D-finite element mode.

4 RESULTS

4.1 Hydraulic model setup

The 1D/2D-model utilises the official 25 m resolution DEM of Germany for the floodplain inundation part. The river bed elevation and slope was extracted from bathymetrically surveyed cross sections of the river in the reach. The model assumes a rectangular channel, which was defined from the surveyed bank widths and bed elevations. The spatial distribution of surface roughness coefficients according to Manning is based on the CORINE land cover data (CLC2000). The basic roughness parameters were derived from tabulated values and further modified during the calibration of the model. In the calibration procedure the roughness value assumed for a whole land cover class was modified.

The full 2D-model operates on a mesh of 46,417 nodes and 87,945 triangular elements (Fig. 6). Floodplain and river topography is sampled onto the mesh using nearest neighbours from the 25 m DEM, and in addition some channel and bank node elevations are taken from channel surveys and linearly interpolated between 18 cross sections. Channel plan form and the extent of the domain are digitised from 1:25,000 maps of the reach. The spatial roughness coefficients distribution was introduced in a similar procedure as in the 1D/2D-model.

4.2 Hazard assessment

Figures 7a-d show the results of the benchmark scenario and the hydraulic models. It can be seen that all models match the inundation extent very good. This visual impression is also corroborated by the flood area index, defined as the ratio between the union area of simulated and mapped inundation to the intersection area of simulated and mapped inundation, of more than 93% of all models (Tab. 2). However, due to the specific morphology of the flood plain, which is a rather flat valley confined with steep hillslopes on both sides, this indicator is not very meaningful. The simulated inundation depth at the valley sides could differ several meters without changing the inundation extent and thus the flood area index. Especially the interpolation method profits from this peculiarity.

Better indexes are the mean absolute error (MAE), the root mean square error (RMSE) and the bias of the simulation results from the measured maximum inundation depths at approx. 400 buildings located in the city centre. Figure 8 compares the simulated and observed water levels in a scatter plot and illustrates the biases of the models. The 1D/2D-simulation performs best with a small bias of -0.05 m and a MAE of 0.60 m (Tab. 2). Thus the performance of the 1D/2D approach is comparable to the benchmark scenario, which has a bias of 0.05 m and a mean absolute error of 0.61 m.

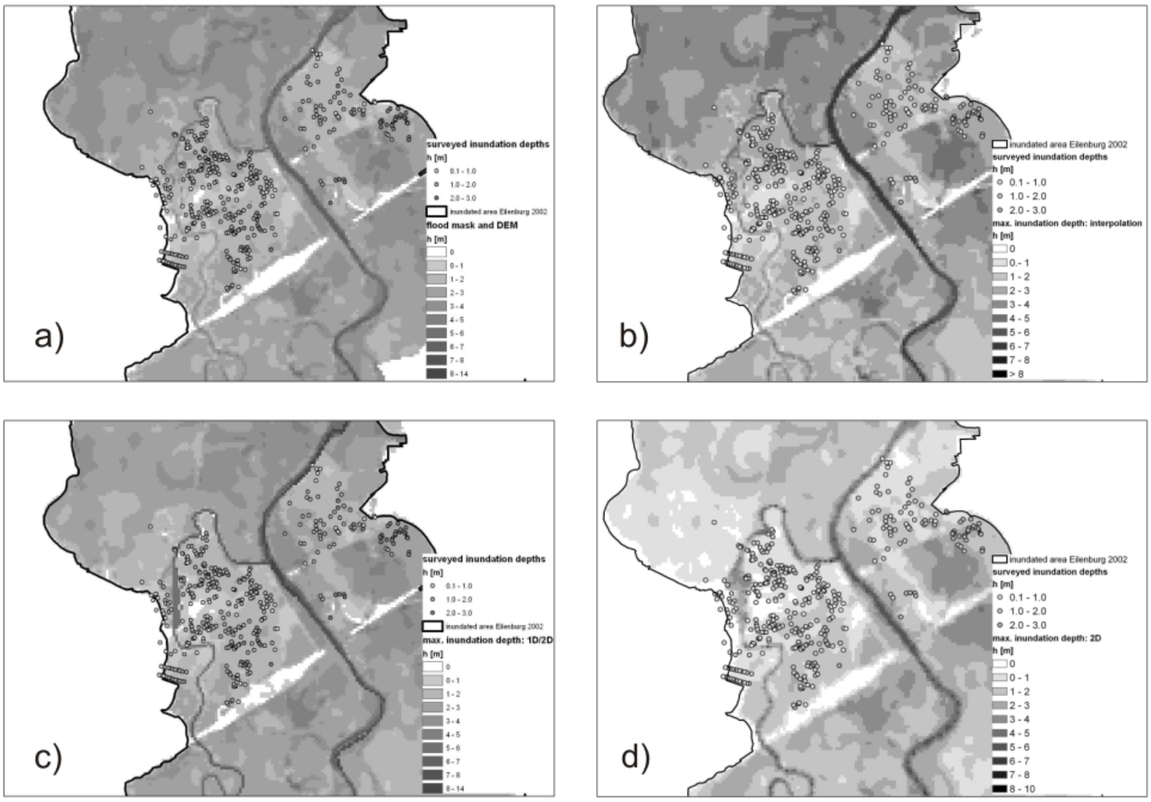

Fig. 7: Results of the hazard models: a) cut and fill DEM, b) linear interpolation, c) 1D/2D-model, d) 2D-model.

Tab.2: Performance of the hazard models in simulating the flood of August 2002.

Performance / Model	surveyed inundation depths			flood extent
	bias [m]	mean absolute error [m]	root mean square error [m]	flood area index [%]
flood mask and DEM	0.05	0.61	0.97	100
linear interpolation	0.28	0.60	0.82	96.43
1D/2D-hydraulics	-0.05	0.60	0.88	96.05
2D-hydraulics	-0.62	0.80	0.93	93.36

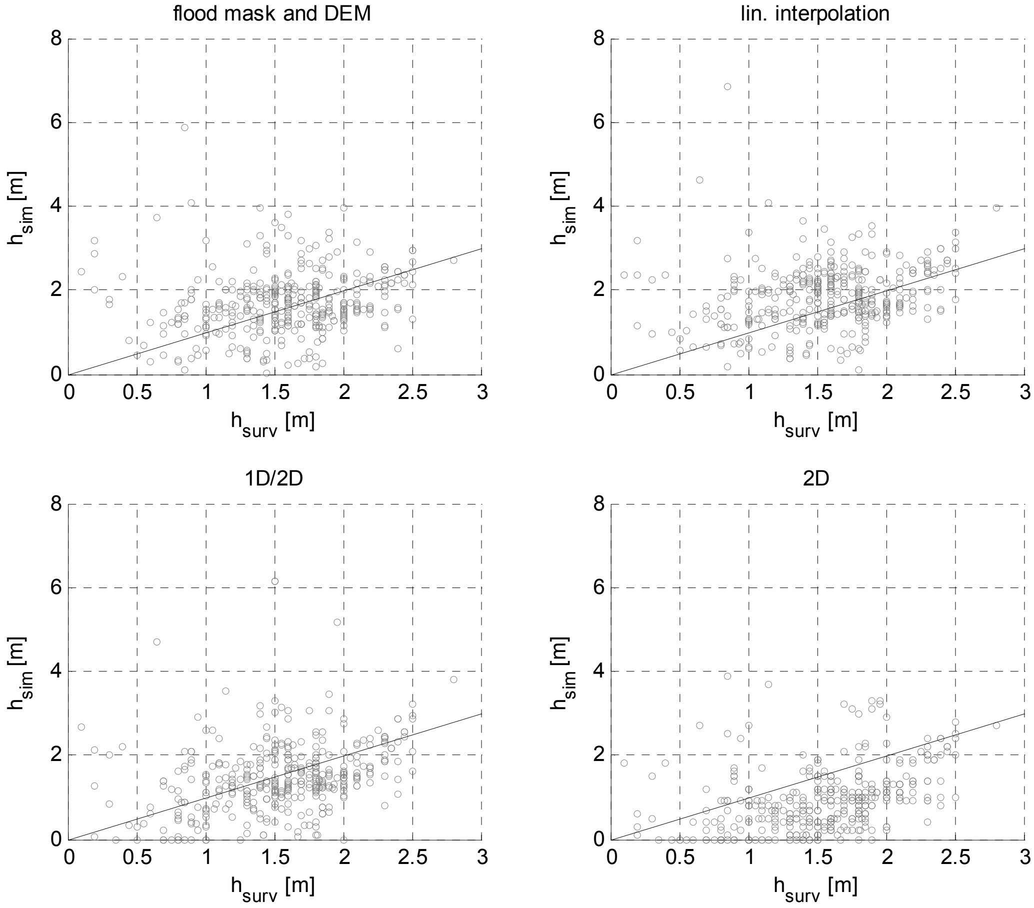

Fig. 8: Scatterplot (Bias) of the surveyed inundation depths vs. simulation results at 400 buildings.

The bias of 0.28 m of the interpolation method indicates that this approach systematically overestimates the inundation depths, especially smaller depths (Fig. 8). However, the bias of the 2D-model is even higher, but in the opposite direction: On average, the model underestimates the inundation depths by -0.62 m. This is possibly caused by an incorrect representation of the river bed elevations in the mesh (i.e., width) in the full 2D-model or a matter of further calibration, which is restricted by the long simulation time. Fig. 8 also shows some extreme overestimations of 3-5 m at the same points for all models. At these points the quality of the DEM has to be questioned, rather than the quality of the simulation results. Considering this, we also calculated the model performance statistics using only data points with an absolute difference surveyed – simulated inundation depths of less than 2 m. This had only little influence on the performance of the interpolation method and 2D hydraulics, but it increased the bias of the 1D/2D model to -0.12 m while improving the bias of the flood mask scenario to 0.02 m.

The runtimes of the models differed significantly, as expected from the complexity levels. The full 2D-model required approximately 10 hours to simulate the 5 day flood wave, whereas the 1D/2D-model needed about 20 minutes. Also, the time needed for the model setup is significantly larger for the full 2D-model, because it doesn’t operate directly on the DEM, but on a mesh required by the finite element code, which has to be constructed from the DEM first. Additionally, the imprinting of the real channel geometry in the mesh deduced from cross section surveys has to be done carefully, which is again more time consuming than in the case of the 1D/2D-model. The simulation time of the interpolation model is more or less the time required for the preparation of the input data and the intersection of the flood levels with the DEM. This usually needs a number of verification steps, which can hardly be automated, until a satisfactory result is obtained. Therefore the preparation time has to be estimated in the range of one to several days.

4.3 Damage estimation

The damage estimates on the basis of the three hazard models and the benchmark scenario on the one hand and various damage models on the other hand are summarised in Table 3. The relative errors from the official damage information of 77.12 million Euro are given in Table 4, the absolute errors in Table 5. However, in order to have more objective rejection criteria, a resampling method (bootstrap) was performed with the 765 damage records in order to derive a confidence interval associated to the total damage figure. The data set was resampled 104 times yielding a median of 76.89 million Euro, a 2.5-percentile of 72.00 million Euro and a 97.5-percentile of 83.39 million Euro. We further assumed that only model combinations with an estimated loss falling within this 95% confidence interval are accurate enough. With this assumption only four model combinations can be accepted:

- the 1D/2D- hydraulic model in combination with the meso-scale damage model FLEMOps+ considering water level, building type and quality as well as contamination and precaution (this model combination achieved the best estimate),
- the linear interpolation in combination with the micro-scale damage model #1,
- the benchmark scenario in combination with the meso-scale damage model FLEMOps+, and
- the benchmark scenario with the micro-scale damage model #1 (see also Tab. 3).

A MRE of 10%, resulting from the combination of the full 2D-model and the stage-damage function HYDROTEC as well as from the linear interpolation and FLEMOps+ (see Tab. 4), can only be accepted if a range of more than 99% of the resampled data is used for model acceptance/rejection.

Thus, with the proposed rejection criteria only two damage models - FLEMOps+ and the micro-scale model #1 - can be accepted. This result is confirmed by further model validations in Saxony presented in Olschewski (2007). Tab. 3 and 4 demonstrate that some damage models in combination with the benchmark scenario tend to underestimate the damage (ICPR, MURL, FLEMOps), while others (HYDROTEC, Micro #2) tend to overestimate. In general, this performance can also be found when the three other hazard scenarios are used. However, the slight overestimation of the hydraulic situation by the linear interpolation is compensated by an underestimation of the damage using the Micro #1 damage model. The opposite holds for the full 2D-model, e.g. in combination with the stage-damage function

HYDROTEC: The underestimation of water depths is compensated by an overestimation of the flood damage, and delivers a fair result (Tab. 4, Tab. 5). We have to conclude that one gets right results with these combinations, but for wrong reasons.

If the mean relative (MRE) and absolute errors (MAE) are calculated per damage and per hazard model (as done in Tab. 4 and Tab. 5) then the following aspects can be retrieved: From all damage models the meso-scale model FLEMOps+ performs best, i.e. it produces the lowest MRE as well as the lowest MAE. The second best model is the micro-scale model #1, the third best the stage-damage function HYDROTEC. The micro-scale model #1, however, shows a higher standard deviation of the MAE. This indicates that the model reacts more sensitive to changes in the inundation pattern and depths.

The worst results were obtained with the stage-damage function MURL and ICPR. These models grossly underestimated the building damage in Eilenburg. The low standard deviation for the MURL-model reflects that the model hardly reacts to differing water levels as is illustrated in Fig. 2. On the opposite, the micro-scale model #2 tends to overestimate the damage. In general, the application of the micro-scale models is hampered by the poor information about the building use and building types in the land register. Therefore, building types were assigned on the basis of the building area and geometry. Probably, too many buildings were classified as multifamily houses by this procedure resulting in high damage estimates of micro-scale model #2.

In comparison to the heterogeneous results of the damage models the MAEs for the three hazard models are quite similar. The overall performance fits to the performance evaluation shown in Fig. 8. However, the amounts of the MAEs as well as the standard deviations are much higher than the MAEs and standard deviations of most damage models (Tab. 5). It therefore has to be concluded that the total damage estimates are more influenced by the choice of the damage model than by the choice of the hydraulic model.

Tab. 3: Estimated damage (given in Million Euro) at residential buildings in Eilenburg due to the flood event in August 2002.

	Damage model						
Hazard scenario	ICPR	MURL	HYDRO-TEC	FLEMO ps	FLEMO ps+	Micro #1	Micro #2
flood mask and DEM	34.91	10.37	97.88	50.40	79.63	72.38	103.29
Linear interpolation	39.75	11.47	105.88	53.78	84.97	76.59	109.02
1D/2D-model	34.50	9.78	95.03	48.68	76.92	67.50	94.67
2D-model	16.82	6.04	69.32	35.03	55.35	46.47	67.42

Tab. 4: Relative errors (given in per cent) of the estimates from the reported building repair costs of 77.12 Million Euro. Abbreviations: Hazard scenarios: O: flood mask and DEM, A: linear interpolation, B: 1D/2D-model, C: 2D-model; MRE: Mean relative error, SD: Standard deviation.

	Damage model								
Hazard scenario	ICPR	MURL	HYDRO-TEC	FLEMO ps	FLEMO ps+	Micro #1	Micro #2	**MRE**	**SD**
O	-55%	-87%	27%	-35%	3%	-6%	34%	**-17%**	**44%**
A	-48%	-85%	37%	-30%	10%	-1%	41%	**-11%**	**46%**
B	-55%	-87%	23%	-37%	0%	-12%	23%	**-21%**	**41%**
C	-78%	-92%	-10%	-55%	-28%	-40%	-13%	**-45%**	**32%**
MRE	**-59%**	**-88%**	**19%**	**-39%**	**-4%**	**-15%**	**21%**		
SD	**13%**	**3%**	**21%**	**11%**	**17%**	**17%**	**24%**		

Tab. 5: Absolute errors (given in Million Euro) of the estimates from the reported building repair costs of 77.12 Million Euro. Abbreviations: Hazard scenarios: O: flood mask and DEM, A: linear interpolation, B: 1D/2D-model, C: 2D-model; MAE: Mean absolute error, SD: Standard deviation.

Hazard scenario	**Damage model**							**MAE**	**SD**
	ICPR	MURL	HYDRO-TEC	FLEMO ps	FLEMO ps+	Micro #1	Micro #2		
O	42.21	66.76	20.75	26.73	2.51	4.74	26.17	**27.12**	**22.16**
A	37.37	65.65	28.76	23.35	7.84	0.53	31.90	**27.91**	**21.23**
B	42.62	67.34	17.90	28.44	0.21	9.62	17.55	**26.24**	**22.59**
C	60.31	71.08	7.81	42.09	21.78	30.65	9.70	**34.78**	**24.38**
MAE	**45.63**	**67.71**	**18.81**	**30.15**	**8.08**	**11.39**	**21.33**		
SD	**10.07**	**2.36**	**8.65**	**8.24**	**9.67**	**13.37**	**9.74**		

5 DISCUSSION AND CONCLUSIONS

All hydraulic models were able to simulate the maximum water levels of the August 2002 flood within certain accuracy levels. The 1D/2D-model gave the best overall performance, with good matches to the surveyed inundation depths and extent, with only little bias. The overall performance of the 1D/2D-model is comparable to the benchmark model. The interpolation method worked also well in this case, but produced a significant bias by overestimating especially small inundation depths. This is a result of the neglect of hydrodynamic features, which is inherent to the method. Despite the comparatively good results of the method it has to be kept in mind that the method cannot be applied to both mountainous areas and flat lowland regions where hydraulic characteristics and volume control significantly influence flood extent and inundation depths. The performance of the full 2D-model, which should principally be able to produce similar results as the 1D/2D-model suffered from the complex model setup, requiring detailed spatial river morphology data, and the long simulation times preventing a thorough calibration of the model. This problem is very often encountered in working with 2D hydraulic models, especially when the resolution of the underlying DEM is coarser than the width of the channels.

However, the variability of the hazard modelling results is small in comparison to the variability of the damage estimates as shown in Table 4 and Table 5. It has to be concluded that the selection of the damage model has a much larger impact on the final risk estimate than the selection of the hazard model. In this respect the meso-scale damage model FLEMOps+ including additional factors (oil contamination, precaution) yielded a remarkable improvement of the damage estimation in this case study, as compared to simple stage-damage functions. The micro-scale damage models did not yield comparable or even better results than the meso-scale model FLEMOps+ since their application was hampered by rough assumptions about the uses and types of the affected buildings. These results can only be improved by a field survey of the building stock or by help of satellite images.

The study also showed the necessity of evaluating the performance of the hazard and vulnerability models separately from each other. Otherwise apparently reasonable damage estimations can be achieved, but for wrong reasons. This means that the error caused by the hazard model could be compensated by errors of the vulnerability model. While this may be regarded as a pragmatic solution for the problem at hand, it will surely cause problems when a temporal as well as spatial transfer of the approach is intended, besides the fact that such a solution is not acceptable from a scientific point of view.

As a summary it can be concluded from this case study, that the 1D/2D-hydraulic model in combination with the meso-scale damage model FLEMOps+ is the best compromise between data requirements, simulation effort, and an acceptable accuracy of the damage estimation and would be our recommended approach for a thorough flood risk assessment in the area. The use of water masks intersected with a DEM in combination with FLEMOps+ also proved to be an efficient method for flood damage estimation. This method would be a good choice for quick damage estimations shortly after a flood.

However, since this paper presents only a case study, further test cases in other regions should be undertaken to corroborate the general applicability of this conclusion. The need for further tests and validations underlines the necessity of a thorough documentation of flood events concerning the flood characteristics as well as the flood losses.

References can be found at the end of the thesis.

SECTION III:

FLOOD RISK MANAGEMENT IN GERMANY

Paper 9: Flood risk reduction in Germany after the Elbe 2002 flood: aspects of hazard mapping and early warning systems

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Abstract

Severe floods hit Central Europe in August 2002. In Germany, 21 people were killed and the estimated costs amount to about € 11.8 billion. Initiated by the German Committee for Disaster Reduction (DKKV) an interdisciplinary „lessons learned"-study was carried out for the Elbe flood with the aim to evaluate strengths and weaknesses of the current flood protection and to give recommendations for improved flood mitigation in Germany. In this paper the methodological framework and some results in the fields of hazard mapping and early warning are presented.

The analysis shows that there is a huge lack of standardisation in flood hazard mapping in Germany, of considering extreme events and of linking hazard zones with land use planning. There are first attempts to close this gap. However, further integration and standardisation of data and information is needed.

In case of a flood, real-time information about the hazard is needed to save people and their property. During the August 2002 flood, warnings were often lacking, too late or incomplete so that affected people did not know what was happening and how to protect themselves and their assets. To secure adequate reaction people have to be better informed about hazards, risks and appropriate behaviour. Therefore, it is suggested to enable public access to hazard maps in order to strengthen public risk awareness.

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1 INTRODUCTION

The low-pressure system "Ilse", a Genoa Cyclone Type Vb-weather system, brought lasting and heavy rainfalls resulting in devastating floods in Germany, Austria, the Czech Republic and Slovakia, particularly in the catchment of the river Elbe in August 2002. In Germany, 21 people were killed and substantial parts of the infrastructure were destroyed. Damage estimates now amount to € 11.6 billion for Germany. The most affected German federal state was Saxony. There, the total flood damage was first estimated to be € 6 billion, which was corrected to € 8.6 billion in September 2003 (BMI, 2002; SSK, 2003). Saxony is followed by Saxony-Anhalt with a damage of € 900 million and Bavaria with € 200 million damage (BMI, 2002).

This tremendous damage exemplifies the vulnerability of our highly engineered and organised society to natural hazards and thus emphasises the need to upgrade flood risk management. Initiated by the German Committee for Disaster Reduction (DKKV) a "lessons learned"-study was carried out for the Elbe flood. An interdisciplinary team analysed strengths and weaknesses of the current flood risk management in Germany and developed recommendations for substantial improvements. The final report (DKKV, 2003) as well as an English summary are available on the internet (www.dkkv.org/ver/schrift.asp). In this paper the methodological approaches as well as important results and conclusions of the study will be presented. Emphasis is placed on hazard mapping and early warning systems.

2 METHODOLOGICAL ASPECTS

2.1 Framework for the Analysis: the Disaster Cycle

For the analysis how disasters affect a society the disaster cycle offers a valuable framework. It shows consecutive phases that a society undergoes after it was hit by a disaster. In the "lessons learned"-study two main phases were distinguished: disaster response and disaster risk reduction (Fig. 1).

When a disaster occurs, immediate responsive measures will be undertaken with the priority objective to limit the effects and the duration of that event. This kind of response includes alerting, rescuing victims and taking care of them, as well as immediate measures to prevent further damage and to temporarily recondition important infrastructure (PLANAT, 2004). The type and the effectiveness of these measures depend on the preparedness of the society at risk. A community with few disaster management facilities is less prepared and more vulnerable than a community that has been able to develop a good disaster management, e.g. as a consequence of experienced disasters. The immediate response is followed by a period, in which the affected community tries to repair damage and to reconstruct buildings and infrastructure in order to regain a standard of living similar to that before the disaster happened (PLANAT, 2004). The way of reconstruction is setting the stage for the society's next "disaster". If the affected area is rebuilt as it was, with little attention to land use regulation, building codes etc., then its vulnerability is replicated (Olsen, 2000). In this case, the area is likely to experience a similar disaster if an event with a comparable intensity occurs. If an affected community is, however, willing to learn from a disaster there will be a period of disaster risk reduction. Documentation and analysis of the disaster as well as of the disaster response is a pre-condition for such a learning process and should thus be an element of disaster response.

The phase of disaster risk reduction consists of preventive and precautionary measures that help to minimise the hazard as well as the vulnerability of people and assets. Whilst prevention aims to avoid damage e.g. by appropriate land use regulation in hazard-prone areas, precaution intend to minimise damage by building up capacities that help to manage adverse effects of a catastrophe. If the phase of disaster risk reduction is successfully accomplished and maintained, then it is very likely that the next severe event will not result in a disaster but only in a severe, but manageable emergency (Olsen, 2000).

In the "lessons learned"-project the following measures were identified to be relevant for flooding (Fig. 1): Measures that enhance the natural water retention in the catchments and technical flood defence aim to minimise runoff and to manage water flows. Non-structural measures like land use regulation and building codes in flood-prone areas aim to prevent flood damage. If inundation of settlements cannot be completely avoided then losses can be minimised by building precautionary measures and early warning systems which induce people to undertake appropriate emergency measures. Preparedness can be enhanced by public information, training and exercises. Finally, insurance against flood damage helps people and enterprises to recover from flood damage fast.

In this paper special emphasis is placed on two fields, where information technology and cartography can play a crucial role: land use regulation and hazard mapping as well as early warning systems and public information.

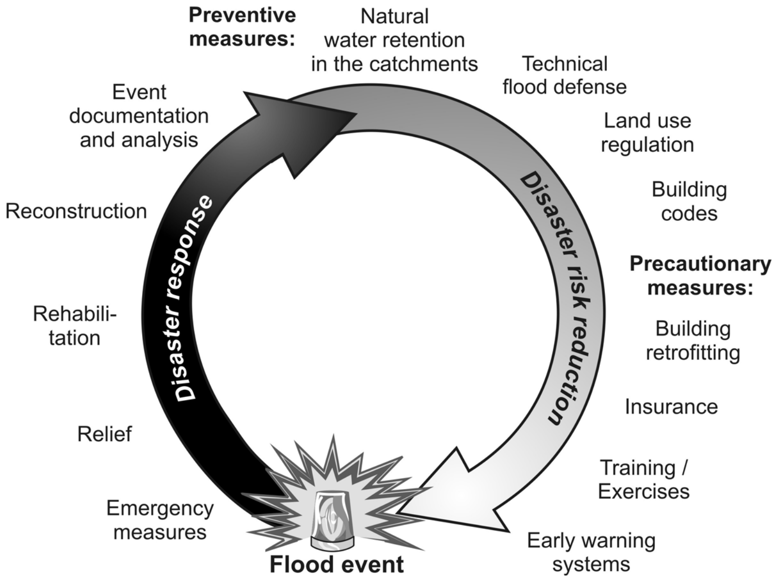

Fig. 1: Concept of the disaster cycle adapted to flood risk (modified from DKKV, 2003).

2.2 Case studies and data

The elements of the disaster cycle were analysed in the catchment of the river Elbe, particularly in five regions, which serve as case studies: the valley of the river Mueglitz, the city of Dresden, the towns Bitterfeld and Dessau and the system of the Havel polders. In these case study regions documents and reports of the flood event 2002 were gathered and experts, e.g. from the water and planning agencies, were interviewed. Furthermore, data from a survey among private households affected by the August 2002 flood undertaken by Kreibich et al. (2005a) could be used for this study. Moreover, a survey among insurance companies was undertaken. Besides, deployment reports of different civil protection units, relief organisations and support units were evaluated by a content and a network analysis. Deployment reports indicate who communicated or cooperated with whom and in what circumstance. The frequency and intensity of such relations allow conclusions on how the participants interacted with each other, with their resources and the actual circumstances. Further details can be found in DKKV (2003).

3 RESULTS AND DISCUSSION

3.1 Land use regulation and flood hazard mapping

The most effective means to reduce flood damage potential is to prevent the development of settlements, industrial areas and infrastructure in flood plains by spatial planning. Further, land use regulation should restrict an increase in damage potential and permit only adapted use in flood-prone areas e.g. by imposing building codes or other restrictions. Ideally, land use regulation should be balanced with the flood hazard, which is the intensity of flood events e.g. given in water levels and flow velocities combined with their exceedance probability. The higher the flood hazard is the more restrictive land use regulation should be applied (Petraschek, 2002). This idea is realised in Swiss hazard maps (BUWAL, 1998): A matrix of flood hazard zones is built from the combination of three flood intensity classes (i.e. product of water level and flow velocity) and three event probability classes (Fig. 2). The resulting flood hazard zones are directly linked to land use regulations. In prohibition areas construction is generally not allowed. In command areas construction is allowed under certain restrictions. In advice areas construction is possible, but recommendations for adapted building design are given. The (residual)-risk zone covers areas where floods might occur but with a very small likelihood. Sensitive objects, e.g. schools, should not be built in such zones.

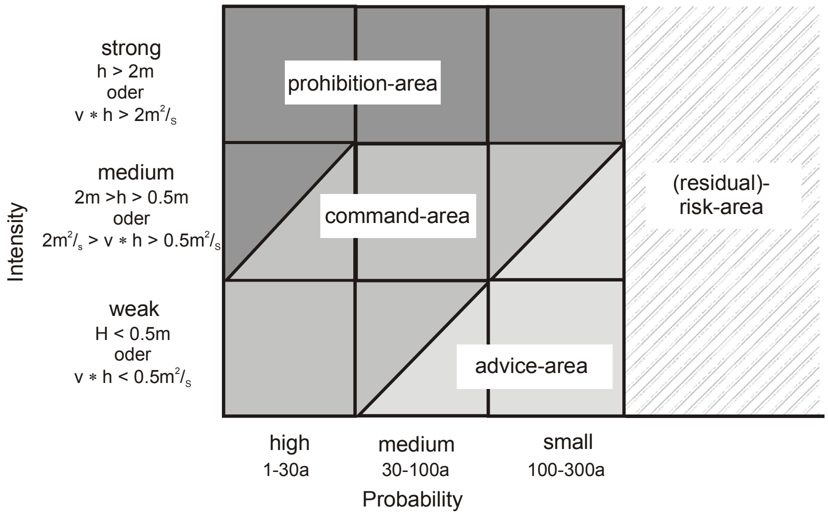

Fig. 2: Intensity-probability-matrix for the assessment of hazard-prone areas (danger zones) as basis for land use planning in Switzerland with h: water level and v: flow velocity (modified from BUWAL, 1998).

In Germany, a standard system for flood hazard and risk mapping and for considering hazard zones in land use regulation does not exist. There are several administrative levels, which are relevant for land use planning in Germany (Fig. 3). Guidelines and directives of the European Union (EU) are implemented at the federal level of Germany, which provides a framework of regulations for all federal states. The German Basic Constitutional Law (Article 28) commits the German government to granting the federal states an adequate scope for legislation in their territories (Turowski, 2002). The federal states in turn are obliged to allow their regional administration units and finally the communities flexibility in their decision-making unless there are binding mandatory regulations, which have to be followed throughout the regional and urban planning processes. The principle of countervailing influence ensures the implementation of federal regulations at the communal level as well as the consideration of communal interests at the federal level. Due to this system, each federal state has its own Water Resources Act, Planning Act and on this basis its own Regional Plan, etc. If a planning authority at a certain level defines a more specific land use than it is usually allowed to do, it has to be of supra-local or higher significance; otherwise the planning autonomy of the lower level would be violated.

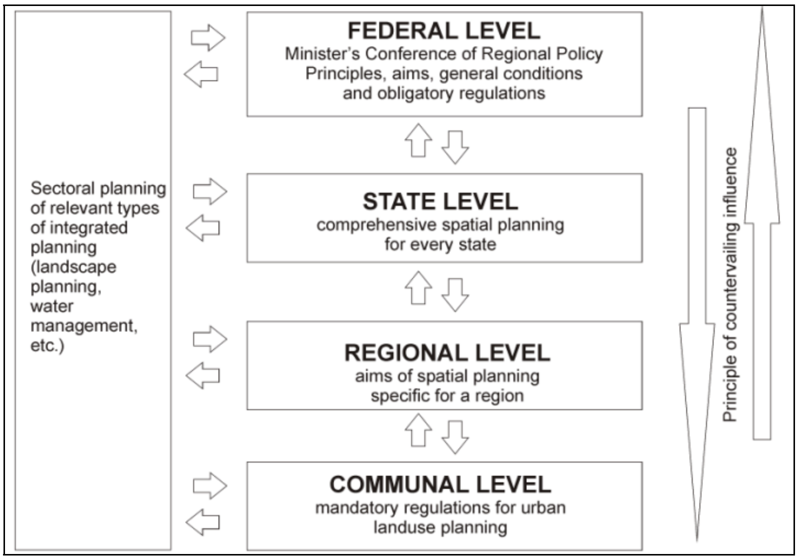

Fig. 3: Levels of and interaction in the German spatial planning system (modified from BBR, 1996).

Local authorities develop statutory plans for the regulation of the communal interests within their administrative borders. With the help of preparatory development plans and binding development plans the communal authorities assign a certain land use to a specific land parcel. Therefore, the communal level plays the key role in land use regulation for disaster risk reduction. However, communities are also dependent on the trade taxes they charge. For example, if a community convinces an investor to settle within its area and to develop a large enterprise instead of choosing a neighbouring community, the community gains trade taxes – one of the most important incomes at the communal level. Frequently, open areas are available in flood-plains. Given scarce communal budgets, this conflict between flood damage prevention and economic development often leads to a disregard of flood risk management demands.

A number of severe floods hit Germany and Central Europe already during the 1990ies (e.g. Rhine 1993 and 1995, Odra 1997, Upper Rhine and Danube 1999, Wisla 2001). As a consequence of these events, planning authorities in some states of Germany started to tighten area precaution measures and developed regulations at the regional and state planning levels. This included the establishment of flood hazard maps. However, hazard maps differ between federal states with regard to their information content, the included events, their spatial extent (in some states there is only information for some communities), the accessibility for the public and the implementation in land use planning.

In several states of Germany, e.g. Bavaria, Baden-Wuerttemberg, Hesse or Saxony-Anhalt, flood hazard maps show the expected flooded area for a 100-year flood event. In Bavaria, for example, these maps are published in the internet (www.bayern.de/lfw/iug/kart.html). The limitation to the 100-year inundation area has the big drawback that it may imply that people are safe beyond the 100-year flood line. Therefore, the hazard maps in Saxony-Anhalt are supplemented by a second zone, which shows the extent of inundation if all technical flood defence fails (Fig. 4). Although this kind of map already delivers more information, further information about other possible flood scenarios, e.g. a flood with a higher return period, is missing. Another major shortcoming is the lack of intensity information (e.g. inundation depth, flow velocity, flood duration) within the flood zones. Such information is extremely useful for flood prevention and emergency management. An example that partly overcomes these shortcomings is the Rhine-Atlas, which shows the extent of a 10-year flood, a 100-year flood and the inundation depth for an extreme flood (200-year flood up to 10.000-year flood) (ICPR, 2001). The Rhine-Atlas is also accessible to the public (www.rheinatlas.de). Similar examples can be found for the cities Cologne, Rastatt and Darmstadt or in the flood action plans for catchments in North Rhine-Westphalia.

In the aftermath of the 2002 flood, the most affected states started to introduce or to extend flood risk mapping schemes and plans for flood prevention measures. For example, the Swiss flood hazard mapping scheme (Fig. 2) is now introduced by the state of Saxony. Hazard maps (scale 1:10000) are developed for every community and for different types of hazard (flood and erosion). They are prepared for different scenarios: 20-year flood, 100-year flood and a more extreme event. This is defined to be either a 500-year flood or a water level, which corresponds to 1.5 times the water level of the 100-year flood (LfUG, 2003, pers. comm.). Based on these maps, the authorities are going to develop generalised hazard maps at the scale of 1:100000. It is intended to merge these generalised maps into a flood hazard atlas for all major rivers in Saxony. This atlas will also include severe historical flood events (LfUG, 2003, pers. comm.).

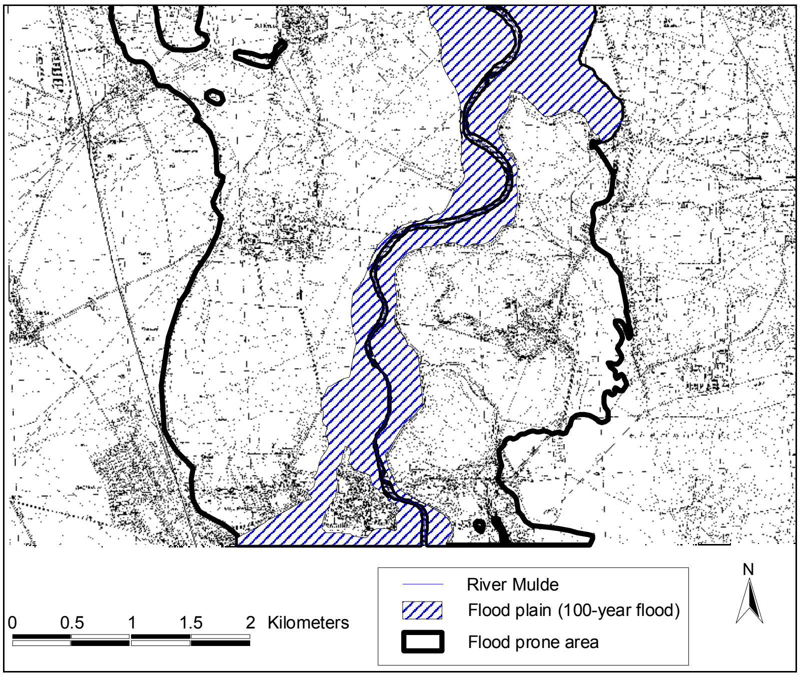

Fig. 4:
Hazard map showing the expected flooded area for a 100-year flood (flood plain) and the flooded area if technical measures fail (flood-prone area) (Data source: Haase et al., 2003).

Immediately after the flood event of August 2002, the German government developed a 5-point-programme, which is aimed at improving preventive and precautionary flood protection measures (BMU, 2003a). Important objectives of the programme are the reactivation of flood zones, the joint establishment of a flood protection programme for the federal and state levels and a more intensified catchment-based flood management. Based on this 5-point-programme, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety developed a Flood Control Act (BMU, 2003b). This draft programme demands amendments in many laws such as the Federal Water Resources Act, the Federal Building Code and the Federal Regional Planning Act. Changes in the Federal Water Resources Act will comprise further regulations for flood plains and flood-prone areas. For the latter, regulations will ensure the identification and the appropriate conservation status of these areas. In the proposed Flood Control Act statutory flood plains are defined as the area affected by the 100-year flood. Flood-prone areas are enlarged to the areas that will be affected if the flood protection fails as shown in Fig. 4. Thus, a consistent country-wide standard for flood hazard information has been defined for the first time. Since the proposed Flood Control Act touches the laws of the federal states (cf. Fig. 3), it will be negotiated in the German Conciliation Committee in February 2005.

However, a standard system for flood hazard and risk mapping has not been developed so far. A first workshop concerning the standardisation of flood hazard mapping was held in November 2004 lead-managed by the LAWA (*Länderarbeitsgemeinschaft Wasser* - German Working Group of the Federal States on Water Issues). Another step towards an enhanced flood protection and river management will be a new uniform federal framework for catchment-based flood protection plans, which will have to be adjusted to international standards. These plans also incorporate measures to deal with a 200-year-flood.

In many countries, e.g. United Kingdom, France, USA, Canada and New Zealand, the area affected by a 100-year flood plays an essential role for flood mitigation (Marco, 1994, Watt, 2000). The benchmark for land use restriction in Germany is most often the 100-year flood, as well. However, the concentration on this benchmark is questionable since it does not release the authorities to consider more extreme events and to communicate that there is a risk even if an area is safe against the 100-year flood. Both, the analyses of extreme flood events as well as the publication of such information are still an exception. Many communities seem to evade the analysis of extreme flood events (beyond the 100-year flood) and its communication with the public. In order to provide sustainable land use planning, extreme events must not be ignored during the local planning process. Authorities often fear the public would be unable to handle the risk and the community could suffer economic consequences from the price decline of flood-prone areas. Thus, some federal states develop hazard maps but their access is restricted to public authorities e.g. for planning and environment. As a consequence, the public may not be aware of the existing hazards and will not invest in precautionary measures. Therefore, the publication of hazard maps is highly recommended.

3.2 Early warning systems and public information

When a flood occurs, real-time information about the upcoming hazard is needed to evacuate people, to make decisions concerning the management and redirection of water flows (civil protection) and to enable people to reduce losses by saving their property. An early warning system can work very effectively: For example, data from floods caused by dam failures show that fatalities are almost prevented if the warning time amounts to at least 1.5 hours (von Thun, 1984 cited in WBGU, 1997).

A successful flood early warning system consists of five components: detecting the situation, developing forecasts, warning civil protection and affected people, taking the correct actions and behaving adapted to the situation (Table 1). However, the whole system is more than a series of components. Although each component should conform to the state of the art, the decisive factor is their interaction. For example, Penning-Rowsell and Green (2000) illustrate that the impacts of flood warnings on flood damage reduction depend on the reliability of flood warnings, the proportion of residents available to respond to a warning, the proportion of residents able to respond to a warning and the proportion of residents who respond effectively. They conclude that benefits of early warning systems can only be realised when the total system of forecasting, warning and responding is operating effectively. Unfortunately, this is frequently not the case. Investments in early warning systems are often slanted towards the development of monitoring and flood forecasting systems, while distribution and implementation of forecasts and warnings are neglected (Grünewald et al., 2001).

Tab. 1: Elements of an early warning system (modified from Parker et al., 1994).

	Activities	Participants, Stakeholder	Factors for success
Collecting data	Collection of meteorological data and forecasts Collection of hydrological and hydrometrical data	Meteorological Services Central and regional water management authorities	Automatic data collection and remote data transfer Weather radar Dense monitoring networks
Forecasting	Data collection and interpretation Flood modelling and forecasting Release of warnings	Flood forecasting centres Central and regional water management authorities	Operational flood forecasting system including a rainfall-runoff model and a hydraulic river model Good transfer of information within countries and across borders
Warning	Receive of forecasts and warnings Interpretation and decision-making Forwarding warnings Providing (public) information Coordination of and cooperation with all participants and the media	Regional and local decision-makers Flood committees Civil protection (rescue service, police, fire brigades etc.) Media	Clear responsibilities 24-hour standby Rapid and efficient communication Long forecasting periods, few false warnings, targeted forecast data Good transfer of information within countries and across borders
Reacting	Coordination of measures and participants Informing the public (alerting)	Flood committees Local authorities Civil protection	Good information systems for the public with feedback
Behaving	Evacuation Flood defence Reducing flood damage by emergency measures	Users of water and water ways (navigation, shipping, wastewater treatment) Companies and industry at risk People at risk Power authorities	Appropriate reaction to information and warnings Availability of help Risk awareness Flood experience

In August 2002, a preliminary warning of a rainstorm was issued on 11th August 2002 at 13:59 CET by the German Weather Service. This was updated to a rainstorm warning at 23:08 CET. Further updated storm warnings were issued from 12th to 14th August 2002. However, a dramatic increase in runoff already occurred on 12th August 2002, e.g. in the rivers Mueglitz and Weißeritz. In such catchments, with an area of less than 300 km², flood forecasting is only possible with prompt precipitation forecasts in conjunction with a suitable rainfall-runoff model. Therefore, it was often criticised that the weather warnings of the German Weather Service in August 2002 were too late and too imprecise. Although the models provided information about impending extreme weather situations that also led to an increased awareness among the forecasting meteorologists, the accuracy of the model output was evidently not sufficient for an earlier warning (Rudolph and Rapp, 2003).

In total, there are 214 flood report and forecasting gauges in the catchment of the river Elbe (IKSE, 2001). However, during the August 2002 flood many automatic gauges, particularly in the Ore Mountains, failed owing to severe inundation or to power black-outs. In addition, the flood forecasting model for the river Elbe is based on a regression analysis of discharges and uses discharges at upstream gauges as input data. Discharges are calculated from the water levels at a particular gauge by means of a rating curve (i.e. stage-discharge-relation). In August 2002 the flood forecasts along the river Elbe were hampered by the fact that the flood reached water levels for which the forecasting model was not calibrated and the rating curves were not defined. Hence, the curves were extrapolated which led to erroneous modelling results. For example, in the reaches of the river Elbe in Mecklenburg-Western Pomerania forecasts exceeded the actual water levels by almost half a meter (Innenministerium Mecklenburg-Vorpommern, 2002). These erroneous forecasts led to the realisation of many elaborate protection measures that in fact would not have been necessary.

There was also a strong criticism regarding the flood reports and their forwarding (cf. von Kirchbach et al., 2002). Forecasts and discharge measurements were often issued without an assessment of the situation or without further instructions. Moreover, at some places forecasts were issued at a time when the actual runoff development was already by far beyond the forecasts. This exemplifies the poor feedback of rural districts to the flood forecasting centres. Furthermore, forecasts were not consistent, e.g. at the river Mulde, since different flood forecasting centres were responsible for this catchment area. In addition, flood reports were delayed at intermediate stations and reached the civil protection agencies too late.

As far as the disaster response system is concerned the analysis of deployment reports showed that different authorities responsible for civil protection, relief organisations and support units do not really cooperate but primarily act in an organisation-oriented and resource-driven way. Predominantly each participant gets involved with the others in his or her organisation, i.e. public authority to public authority, fire brigade to fire brigade etc. The analysis of the key dimensions “communication”, “cooperation”, “use of resources” and “management process” revealed four structural failings:

- poor relatedness between different organisations relevant for civil protection (lack of points of contact)
- dominance of self-orientation and a lack of orientation towards the situation as a whole and to superior protection objectives (lack of knowledge about the

qualification and equipment of other organisations, missing consideration of complementary equipment or activities)

- weaknesses of the authorities in civil protection to assess knowledge, motivation, capabilities and capacities of the individual organisations
- isolation and centralisation of the operative-tactical subsystem making innovations difficult.

The deficits in flood forecasting and warning are also reflected by the fact that in a survey among affected private households (Fig. 5A) about 40% of interviewed people at the Elbe tributaries were not warned. This percentage drops to 10% along the river Elbe. 60% of the interviewed people along the river Elbe received a warning from local authorities, whereas along the Elbe tributaries this is true for only 29% of the interviewees (Fig. 5B). Official warnings were investigated in more detail. The survey revealed that one fifth of the warnings contained no detailed information about the flood hazard (water level, time to peak etc.) and possible mitigation measures. As a consequence people's knowledge about how to protect themselves and their households against the flood water was rather low: On a scale from 1 (= I knew exactly what to do) to 6 (= I had no idea what to do) only 25% of the people chose a "1" or "2" (Fig. 5C).

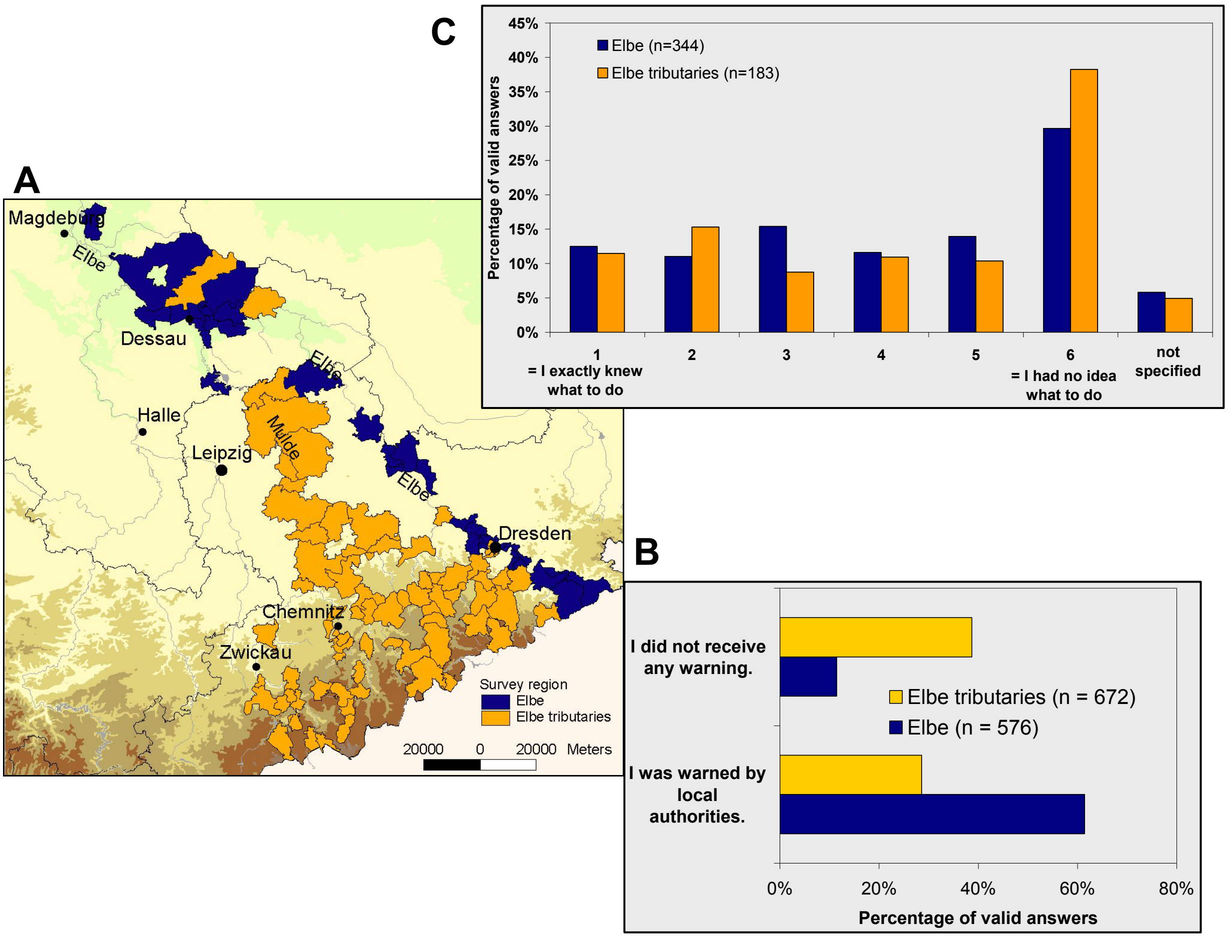

Fig. 5: Flood warning in August 2002: Results of a survey among 1248 affected private households in the Elbe catchment (data from Kreibich et al., 2005a). A: Surveyed zip code areas. B: Warning of affected private households in August 2002. C: People's knowledge how to protect themselves and their households against flood water.

Since severe drawbacks in the whole flood warning system came to the fore in August 2002 several activities were launched in the aftermath of the flood: The German Weather Service has continually been improving the numerical weather models, particularly the precipitation forecast, especially by including radar data. Moreover, the monitoring network of automated online precipitation stations has been enlarged to obtain a better spatial differentiation in the forecasts of rainfall depths. Besides, the schedule of releasing warnings was upgraded. Weather warnings can be called up free of charge in the internet. The most affected federal states have also begun to release flood reports, latest water levels and discharges on the internet. Moreover, the four regional flood forecasting centres in Saxony were centralised in one federal flood forecasting centre (*Landeshochwasserzentrum*). In addition, new flood forecasting models are being developed for the river Elbe, e.g. at the European Institute for Environment and Sustainability in Ispra, Italy. Finally, the satellite-aided warning system SatWas has been integrated in public as well as in private radio stations and will provide nationwide warnings of the population.

To overcome the shortcomings of cooperation and communication in civil protection standard national disaster protection regulations should be set up with clear responsibilities, trainings and evaluation procedures. Moreover, nationwide and consistent statistics on the qualification and equipment of disaster protection organisations should be compiled. A first step in this direction is the disaster information system deNIS. However, little is done to strengthen the risk awareness and coping capacity of the population. This shows again that technological aspects are clearly emphasised when improving early warning systems.

4 CONCLUSIONS

The analysis shows that there is a huge lack of standardisation in flood hazard mapping, of considering extreme events and of linking hazard zones with land use planning. The general definition of flood plains and flood-prone areas by BMU (2003b) is a first attempt to close this gap. Its implementation, however, is still uncertain.

It is recommended to develop a standard system for flood hazard and risk mapping and for considering hazard zones in land use planning. Such a system should be valid throughout Germany and should not only consider the 100-year flood, but also more extreme events. Since land use planning is relevant on all administrative levels hazard maps will be of concern for many authorities with different needs and demands. Therefore, mapping standards have to consider different spatial scales and heterogeneous data sources. Early warning systems, on the other hand, make great demands on reliable and time-critical results, on a smooth flow of information and on the preparedness of civil protection and the people at risk. Therefore, forecasts should be based on robust models. The release of warning should follow a predefined flow of information that should be checked up at regular intervals.

In general, flood risk reduction and disaster mitigation are cross-sectional tasks and call for a high degree of cooperation, communication and management. Our analysis reveals that there is no sufficient integrative interaction across sectors and spatial units in the fields of flood risk reduction and emergency response. Information technology can enable or facilitate communication even in extraordinary circumstances. However, a pure technology-driven approach will not solve all problems. To ensure adequate reaction and behaviour people have to be better informed about hazards, risks and appropriate behaviour. Therefore, it is suggested to enable public access to hazard and risk maps in order to strengthen public risk awareness and precaution.

Our society needs a transparent discussion about risks. The basis for this is the publication of hazard and risk maps as well as a consistent debate about protection levels (design standards). For this purpose adequate and precise data are required. Therefore integration and standardisation of data and information should be further stimulated.

References can be found at the end of the thesis.

Paper 10: Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002

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Abstract

In August 2002, a severe flood event occurred in Central Europe. In the following year, a poll was performed in Germany in which 1697 private households were randomly selected from three regions: (a) the River Elbe area, (b) the Elbe tributaries in Saxony and Saxony-Anhalt, and (c) the Bavarian Danube catchment. Residents were interviewed about flood characteristics, early warning, damage, recovery, preparedness and previously experienced floods. Preparedness, response, financial losses and recovery differed in the three regions under study. This could be attributed mainly to differences in flood experience and flood impact. Knowledge about self-protection, residents' homeownership and household size influenced the extent and type of private precautions taken, as well as the residents' ability to perform mitigation measures. To further improve preparedness and response during future flood events, flood warnings should include more information about possible protection measures. In addition, different information leaflets with flood mitigation options for specific groups of people, e.g. tenants, homeowners, elderly people or young families should be developed.

Keywords: flood impact, Germany, mitigation, recovery, flood warning

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1 INTRODUCTION

Damage due to natural disasters has dramatically increased in the last decades. 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 Central Europe (Germany, Austria, the Czech Republic and Slovakia) in August 2002 along the rivers Elbe and Danube and some of their tributaries (see Ulbrich et al., 2003; Engel, 2004). In Germany, 21 people died and substantial parts of the infrastructure were destroyed in some of the affected regions. The most seriously affected German federal state was Saxony, where the total flood damage amounted to €8700 million, followed by Saxony-Anhalt (€1187 million) and Bavaria (€198 million) (data from SSK, 2004; IKSE, 2004; Bavarian Ministry of Finance, personal communication). Altogether, about €11 600 million damage was caused in Germany. This amount by far exceeded the damage due to other disastrous events in Germany, which emphasises the need to improve flood risk management. Many activities have been launched at administrative and legislative levels since the 2002 event (see DKKV, 2003).

In recent years, a shift has taken place from technology-oriented flood defence towards integrated flood risk management (e.g. Takeuchi, 2001; PLANAT, 2004). Flood risk management is aimed at minimising adverse effects and at learning to live with floods (Vis et al., 2003). In general, it focuses on three aspects: (a) flood abatement, with the aim to prevent peak flows, e.g. by an improvement of the water retention capacities in the whole catchment; (b) flood control, aimed at preventing inundation by means of structural measures, e.g. embankments or detention areas; and (c) flood alleviation with the goal of reducing flood impacts by non-structural measures (Parker, 2000; de Bruijn, 2005). The latter can be classified into preventive, precautionary and preparative measures. Prevention is aimed at completely avoiding damage in hazard-prone areas, e.g. by flood-adapted land use regulation. Precaution and preparation help to limit and manage the adverse effects of a catastrophe, and to build up coping capacities by flood-resilient design and construction, development of early warning systems, insurance, awareness campaigns, education, training, putting rescue units on stand-by, etc. (e.g. Vis et al., 2003; DKKV, 2003; PLANAT, 2004; de Bruijn, 2005).

As an analysis of how disasters have affected a society, the disaster cycle offers a valuable framework. The concept has been widely used by international and national organisations and various versions have been published (e.g. DKKV, 2003; PLANAT 2004; FEMA 2004; Kienholz et al., 2004). In this paper, three consecutive phases are distinguished: (emergency) response, recovery and disaster risk reduction (Fig. 1). When a hazardous event occurs, immediate measures are undertaken with the priority to limit adverse effects and the duration of the event (emergency phase). During recovery, the affected society will start to repair damage and to regain the same, or a similar, standard of living as before the disaster happened. This phase sets the stage for the next “disaster” (Olson, 2000): if the affected society is willing to learn from a disaster, there will be a period of disaster risk reduction, in which measures that are aimed at minimising the vulnerability of people and their assets will be implemented. To enhance risk reduction, the disastrous event, the society’s response and possibilities for prevention and preparation should be analysed carefully in the aftermath of an event (Kienholz et al., 2004).

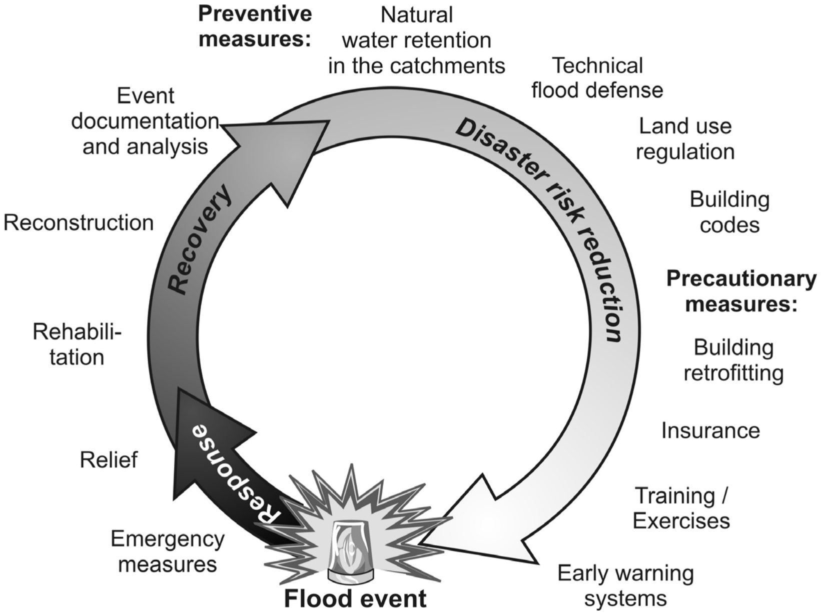

Fig. 1:
Disaster cycle adapted to flood risk (modified from DKKV, 2003).

This paper focuses on the coping capacities of private households in three different regions in Germany. The analysis gives some insight into what people learned from the flood in 2002, and what more could be done to stipulate private precautions and disaster preparedness.

In general, 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). In a survey in Illinois, USA, 68% of 1236 respondents had spent some money on some kind of flood protection. The amount spent was proportional to the property value and household size, but did not depend on the age of the respondent (Brenniman, 1994). A recent study from Japan showed that the residents' preparedness for floods depends on the ownership of a home, fear of flooding and the amount of damage from previous floods, rather than on previous experiences with and anticipation of floods (Motoyoshi et al., 2004). Moreover, socio-economic status is a significant predictor in pre- and post-disaster stages, as well as for the physical and psychological impacts. For example, poor people are less likely to prepare for disasters or buy insurance, but they have proportionally higher material losses and face more obstacles during the phases of response, recovery and reconstruction (Fothergill and Peek, 2004).

A survey among flood-affected people on the rivers Rhine and Danube in Germany showed that floods are perceived as a danger because of their potential damage and because the possibilities for self-protection are perceived as low (see Plapp, 2003; Werner et al., 2003). A further aspect that controls the perception of flood hazard is the perceived ability of the community to cope with the flood (Werner et al., 2003). Therefore, local governments should improve the involvement of residents in flood prevention programmes, e.g. by providing better information about the flood hazard, effective dissemination of flood warnings and communication of the possibilities for private mitigation measures (Krasovskaia et al., 2001, 2007; Werner et al., 2003). To encourage precautionary behaviour in the residents of flood-prone areas, it is essential to communicate not only the flood hazard and its potential consequences, e.g. by flood hazard/risk maps, but also the available private precautionary measures, their effectiveness and their costs (Grothmann and Reusswig, 2006). For example, Kreibich et al. (2005a) showed that different precautionary measures can reduce flood losses up to 50%, even during severe flood events.

Besides long-term precautionary measures, how people react during the disaster and their response to flood warnings can help to limit losses. For example, flood damage due to the Meuse flood in 1995 was 35% lower than that in 1993, when a similar flood hit the same municipalities (Wind et al., 1999). The loss reduction in 1995 may be explained by the increase in warning time and the experiences gained from the 1993 flood. However, Penning-Rowsell and Green (2000) found that only about 13% of potential damage was avoided by flood warnings, since damage reduction depends on the reliability of the flood warning system, and on the proportion of residents (i) available to respond to a warning, (ii) able to respond to a warning and (iii) who responded effectively. They concluded that the benefits of early warning systems can only be realised when the total system of forecasting, warning and responding operates effectively. Therefore, more attention needs to be given to the design of the whole system. Ensuring public response to flood warnings should be just as much the responsibility of the agencies concerned as their role in flood forecasting and warning dissemination (Penning-Rowsell et al., 2000).

The nature of people's reaction to an event might also depend on the type of flooding. People face slow-onset flooding (riverine floods) with elaborate responses, which are not very limited by warning, delay or "labour force" (Torterotot et al., 1992). For fast-onset flooding (flash floods), flood-proofing appears to be the most immediate response, but necessitates a minimum warning because of the speed at which the water rises (Torterotot et al., 1992).

Research from Canada revealed that reduction measures based on designation and mapping of flood plains have had no impact on the occupancy of flood plains, have failed to reduce flood damage, and have not even halted increases in damage (Robert et al., 2003). Successful integrated risk management has to involve different stakeholders (water management, spatial planning, insurers, emergency management, fire brigades, etc.), scientists, NGOs, as well as local residents and companies (e.g. Weichselgartner and Obersteiner, 2002; Pearce, 2003). Disasters—and their mitigation—have to be seen as the products of the social, political and economic environment, as well as the natural events that cause them (Blaikie et al., 1994, p. 3).

Although there are several studies that deal with the vulnerability of people and their willingness and ability to prepare for disasters, we need further knowledge about the vulnerability of people (Brilly and Polic, 2005). Fothergill and Peek (2004) propose—among other things—that in-depth, comparative studies be conducted regarding vulnerability issues in different regions, and that more research be done on risk perception, preparation and warning communication. Therefore, a large survey was conducted following the August 2002 flood in Germany. The main aim of the survey was to identify factors that influence flood damage in the residential sector. This paper investigates how flood-affected private households in three different regions in Germany, which varied in flood type, flood severity, previously experienced floods and socio-economic structure, were able to cope with the flood in 2002. Following the phases of the disaster cycle (Fig. 1), we analysed how private households contributed to disaster mitigation in the three different regions and how preparedness, response and recovery are correlated to socio-economic variables, flood experience and flood impact. The analysis gives some insights into the weaknesses and strengths of the preparedness of residents in the three regions, what people learned from the flood, and, further, what could be done to stipulate private precautionary behaviour.

2 DATA AND METHODS

2.1 Procedure of sampling flood-affected private households

The data set contains information obtained from private households which suffered from property damage due to the August 2002 flood. In April and May 2003, interviews were carried out in 1697 private households in the most affected German federal states, i.e. Saxony, Saxony-Anhalt and Bavaria (Fig. 2).

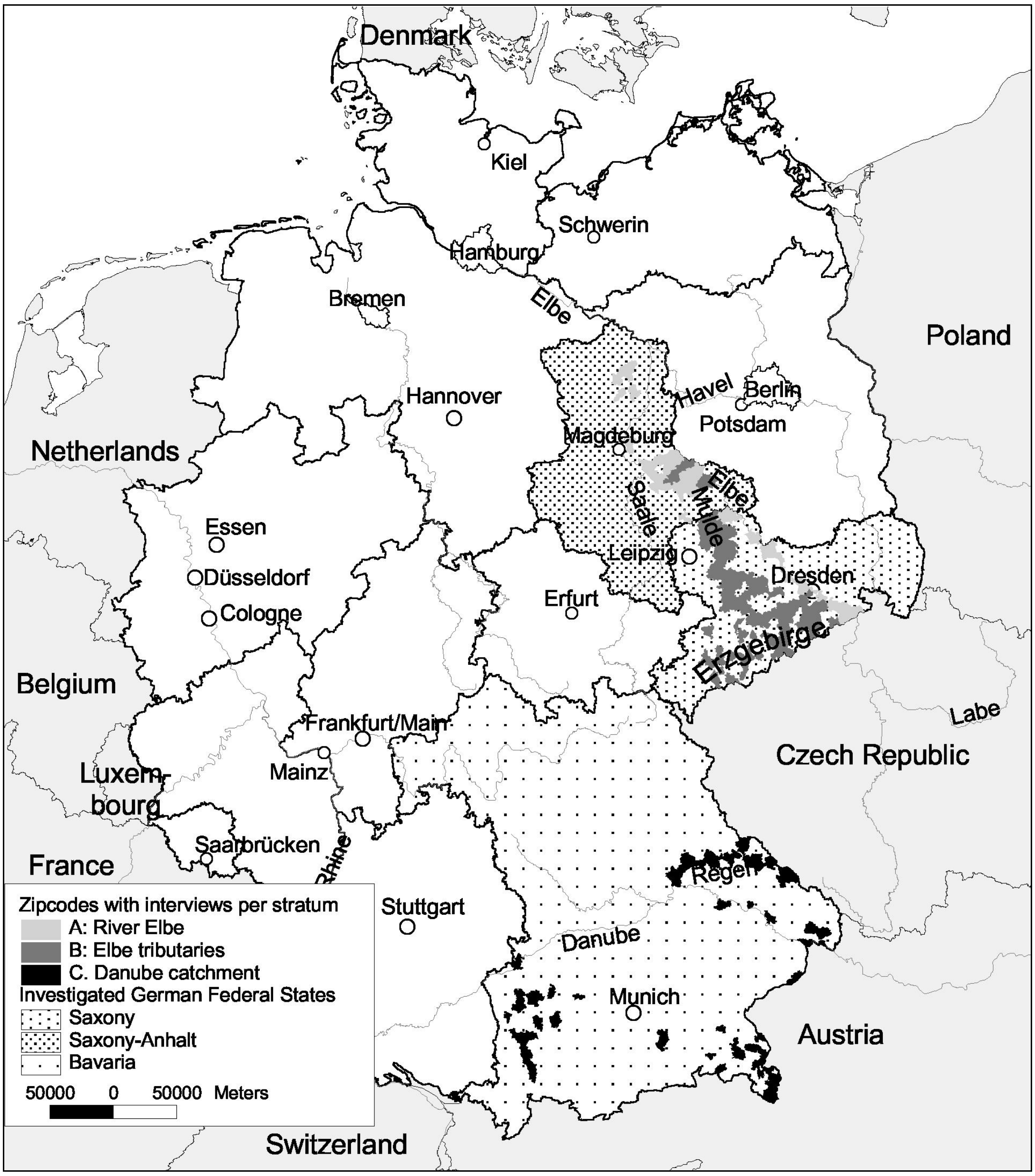

Fig. 2: Areas in which interviews were conducted (Data sources DLM1000, VG250 © BKG, Frankfurt am Main, 2004; ESRIDATA).

The survey was conducted in three regions according to differences in flood type; flood experience and socio-economic structure:

A the river Elbe and the lower Mulde river;
B the Erzgebirge (Ore Mountains) and the river Mulde in Saxony; and
C the Bavarian Danube catchment.

The distinction of these regions was based on the following ideas: during the August 2002 flood, two flood types could be distinguished: slow-onset river floods along the big rivers, and flash floods in the headwaters (see Ulbrich et al., 2003). While riverine floods were predominant along the Elbe and the lower Mulde River (Region A), severe flash floods dominated on rivers in the Erzgebirge (Region B). In Region C, the Bavarian Danube catchment, both flood types occurred.

The flood event was more severe in the Elbe catchment than in the Danube catchment. Return periods in the Elbe tributaries reached 200–500 years (IKSE, 2004). Along the River Elbe, the return period was estimated to be about 100–200 years at the Dresden gauge (IKSE, 2004), but became shorter further downstream due to levee breaches, water detention etc. (Engel, 2004). In the Danube catchment, the flood was most severe on the River Regen, where a return period of 100 years was assigned to the discharge (Gewässerkundlicher Dienst Bayern, 2002).

Furthermore, experiences of previous floods were likely to differ in the three regions. In the Danube catchment, severe flooding occurred in December 1993 ("Christmas Flood") and particularly in May 1999 ("Whitsun Flood"). The Whitsun Flood caused €347 million damage in Bavaria (Müller, 2000). In contrast, the last severe floods on the River Elbe occurred in 1940, in 1954 and in winter 1974/75. However, the water levels on the Elbe in August 2002 were more extreme than before. In the Erzgebirge, widespread flooding occurred in 1954 and 1958. Apart from these events, more localised flooding occurred in several years, e.g. in July 1957 along the River Müglitz, and in winter 1974 on the River Mulde (see Fügner, 2003; Pohl, 2004, for details).

The regions also differ in socio-economic structure, i.e. in income, purchasing power and building structure. For example, the average purchasing power in Bavarian communities amounted to €17 841 per person in 2001, whereas it was €11 555 in Saxony and €11 702 in Saxony-Anhalt, according to census data of INFAS Geodaten GmbH (2001).

On the basis of information from the affected communities and districts, lists of affected streets in the investigated areas were compiled. A random sample was generated on the condition that each street should be represented in the data set at least once and that each building should be included only once. Thus, only one household was selected in multiple-occupancy houses, so that the sample is representative for buildings. In total, 11 146 households (with telephone number) were selected. Computer-aided telephone interviews were undertaken using the VOXCO software package by the SOKO-Institute, Bielefeld, Germany, between 8 April 2003 and 10 June 2003. In each case, the person in the household who had the best knowledge about the flood event was questioned. Tenants were only asked about their household and the content damage. To complete the interview, the building owner was questioned about the building and damage to it. In total, 1697 interviews were carried out; on average, an interview lasted 30 minutes.

2.2 Contents of the questionnaire and data processing

For this investigation, a new questionnaire was designed following the phases of the disaster cycle (Fig. 1) and including suggestions taken from Parker et al. (1987), Penning-Rowsell (1999), Statistisches Bundesamt (1999), Grothmann (personal communication: questionnaire on risk awareness and private precautionary behaviour in flood affected private households used by Potsdam-Institute for Climate Impact Research, Potsdam, Germany), and Schmidtke (personal communication: questionnaire used for recording flood damage for the HOWAS data base at the Bavarian Agency of Water Resources, Germany). Altogether, the questionnaire contained about 180 questions addressing the following topics: flood impact, contamination of the flood water, flood warning, emergency measures, evacuation, cleaning-up, characteristics of and damage to household contents and buildings, recovery of the affected household, precautionary measures, flood experience, as well as socio-economic variables.

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

For flow velocity, contamination, flood warning, emergency measures, precautionary measures (flood-proofing), flood experience and socio-economic variables, indicator variables were generated by aggregation of several items concerning one particular topic. A detailed description of the survey, the data processing and the development of indicators can be found in Kreibich et al. (2005a) and Thieken et al. (2005). The variables and indicators chosen for this paper are listed in Table 1.

Data analysis in this paper comprised the following steps: first, tests were done to establish which variables significantly differ between the three data groups; this was done using the Mann-Whitney U test for two samples and the Kruskal-Wallis H test if all three samples were compared. Significantly differing variables were then analysed in detail for the three regions. Correlations between variables were determined by Spearman's rho (i.e. rank correlation). Only correlation coefficients that were significant at a level of 0.05 and that were equal to or higher than 0.20 are presented herein.

3 RESULTS AND DISCUSSION

3.1 General characteristics of the three data groups

According to the Kruskal-Wallis H test, all variables listed in Table 1 differ between the three data groups at a significance level of ≤0.05, except for the number of elderly people in a household, the perceived quality of the building and the perceived credibility of the flood warning.

To characterise the three groups, statistics of the flood impact, socio-economic variables and flood experience are summarised in Table 2. As expected, socio-economic variables differed less between the groups A and B in comparison to group C (Bavaria). In group C the respondents were a little younger than in the groups A and B, fewer of them had a high school graduation (*Abitur*), but more owned the buildings they lived in. The households in Bavaria were also slightly bigger, as was the mean living area per person. Further, there was a considerably smaller proportion of households with less than €1500 monthly net income (Table 2).

Tab. 1: Items of the survey that were used in this paper.

Item	**Units and labels**
Socio-economic variables:	
Age of the interviewee	Years
Education	Rank from 1 (no graduation) to 5 (high school graduation—*Abitur*)
Household size	Number of people
Children (< 14 years)	
Elderly people (> 65 years)	
Monthly net income of the household	€ (Euro)
Living area per person	m^2
Ownership structure	1:tenant of a flat, 2:tenant of a house, 3:flat-owner, 4:homeowner
Perceived quality of the building/household contents	Rank from 1 (building/household contents are of very good quality or luxurious) to 6 (building/household contents are of poor quality)
Flood experience BEFORE August 2002:	
Previously experienced floods	Number of events
Time period since the last flood event	Years
Indicator of flood experience	Rank from 0 (no experience) to 10 (very well experienced)
Knowledge about the flood hazard of the residence/plot	0: no knowledge, 1: knowledge of flood hazard
Preparedness (BEFORE/AFTER the flood) and risk awareness:	
Acquisition of information about precaution	Number of measures (range: 0 to 3)
Flood insurance	0: no insurance, 1: insurance
Flood-proofing measures and retrofitting	Number of measures (range: 0 to 7)
Perceived efficiency of private precaution	Rank from 1 (flood damage can be significantly reduced by private precautionary measures) to 6 (flood damage cannot be reduced at all by private precautions)
Perceived risk of future floods	Rank from 1 (it is very unlikely that I will be affected by future floods) to 6 (it is very likely that I will be affected by future floods)
Characteristics of the flood in 2002:	
Water level	cm above top ground surface
Flood duration	Hours
Flow velocity	Rank from 0 (no flow) to 3 (very high flow velocity)
Contamination of the flood water	0: no contamination, 1: sewage, 2: chemicals (and sewage), 3: oil (and chemicals or sewage)
Warning and response in 2002:	
Flood warning source indicator	Rank from 0 (no warning) to 4 (official flood warning)
Flood warning information indicator	Rank from 0 (no information) to 14 (detailed information about flood event and advices for damage reduction)
Lead time	Hours
Perceived credibility of the warning	Rank from 1 (warning was absolutely believable) to 6 (warning was absolutely unbelievable)
Perceived knowledge about self-protection	Rank from 1 (I knew exactly what to do) to 6 (I did not know what to do)
Time spent on emergency measures	Hours
People involved in emergency meas.	Number of people
Overall assessment of efficient emergency measures (indicator)	Rank from 0 (no performed emergency measures) to 78 (several efficient emergency measure were successfully performed)
Adverse effects of the flood in 2002:	
Duration of evacuation	Days
Time spent on cleaning-up	Hours
Damage to the building	€
Damage to household contents	€
Recovery:	
Perceived status of restoration of the building/replacement of household contents at the time of the interview	Rank from 1 (buildings/household contents are already completely restored/replaced) to 6 (there is still considerable damage to the building/to household contents)
Compensation received for losses	€

Significant differences in flood experience were also found in the data. Whereas only 9.5% in the group of the River Elbe (A) and 20.2% in the Elbe tributaries group (B) had experienced at least one flood before August 2002, this applied to 41.9% of the people interviewed in the Bavarian Danube catchment (group C) (Table 2). The proportion of people who had experienced a flood in the last ten years was also considerably higher in group C (Table 2). Moreover, only 9.8% of the people with flood experience in group A had already had flood losses of more than €1000, whereas this share amounted to 37.4% in group B and 47.3% in group C. Altogether the experience of floods was highest in group C (recurrent experience), it had been gained more recently, and was combined with financial losses more often than in the other two regions.

The knowledge about being at risk among people without experience of floods was lowest in group B: only 25.5%, in contrast to 35.1% in group A, and 30.1% in group C who knew that they lived in a flood-prone area (Table 2).

The impact of the 2002 flood in terms of water level, flood duration and additional contamination was the most severe in group A. Very high flow velocities were most frequently recorded at the Elbe tributaries (Table 2). Altogether, a broad variation of socio-economic and hydrological conditions was captured by the survey.

Tab. 2: Description of the three data groups with respect to socio-economic variables, previously experienced floods and flood impact in 2002.

Data group	**A**	**B**	**C**	**All**
Name of the group/region	River Elbe	Elbe tributaries	Danube catchment	
Total number of interviews	639	609	449	1697
Socio-economic variables:				
Mean age of the interviewees (years)	54	52	49	52
People with high school graduation (*Abitur*) (%)	24.5%	24.2%	15.8%	22.1%
Mean household size (number of people)	2.7	2.7	3.2	2.8
Households with a monthly net income <€1500 (%)	38.6%	44.4%	25.1%	37.4%
Mean living area per person (m^2)	47.85	44.41	52.84	47.87
Homeowners (%)	74.8%	69.0%	86.6%	75.8%
Flood experience BEFORE August 2002:				
People who experienced at least one previous flood (%)	9.5%	20.2%	41.9%	21.9%
People who experienced a flood in the last ten years (%)	3.6%	7.4%	33.0%	12.7%
People without flood experience, but with knowledge about the flood hazard of their property (%)	35.1%	25.5%	30.1%	30.6%
Characteristics of the flood impact in 2002:				
Mean water level above top ground surface (cm)	113.24	78.57	-25.29	64.22
Mean flood duration (h)	256	102	39	143
Interviews that reported very high flow velocity (%)	1.1%	5.4%	0.7%	2.6%
Interviews that reported oil contamination (%)	49.5%	39.8%	23.3%	39.1%

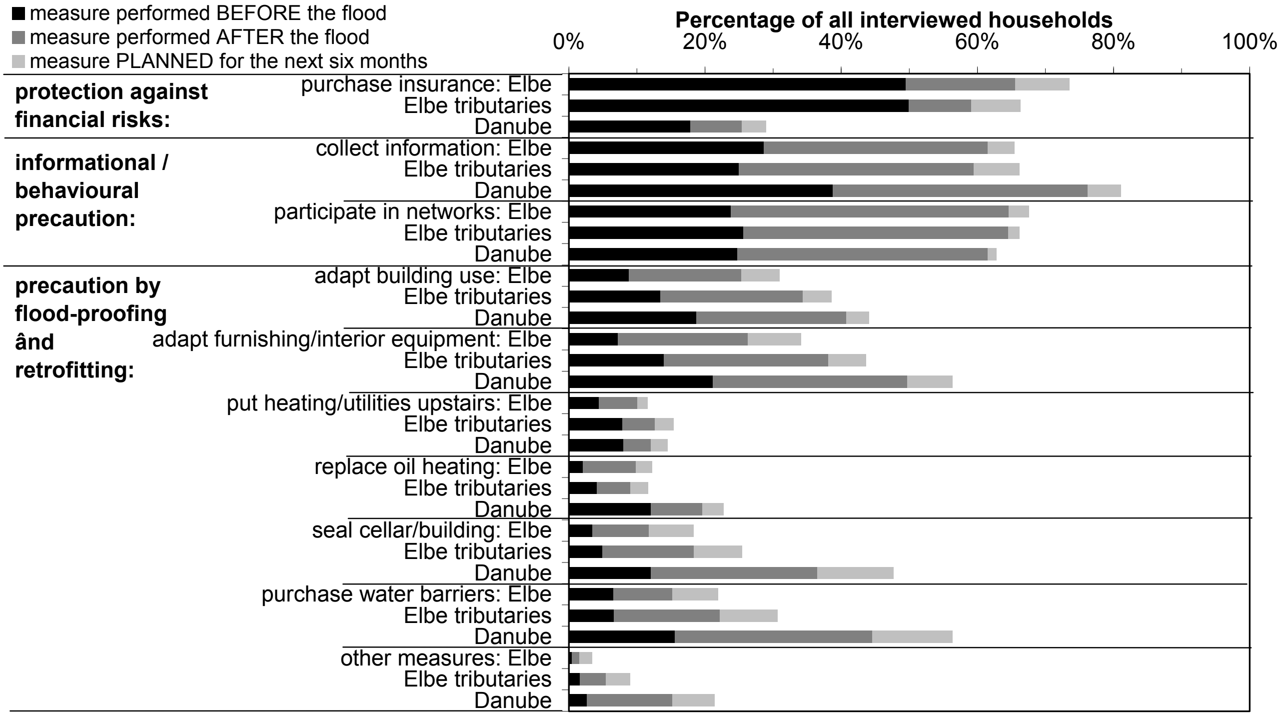

Fig. 3: Precautionary measures undertaken in private households before and after the flood event in August 2002, and measures that are planned for the next six months. Results are given as a percentage of all interviews per region (A: River Elbe: n = 639, B: Elbe tributaries: n = 609, C: Danube catchment: n = 449).

3.2 Preparedness before the flood event in August 2002

Before the flood event in August 2002, 71.2% of the interviewed households in group A, 72.6% in group B and 65.3% in group C had undertaken at least one precautionary action. However, the kind of the measures differed considerably in the three regions (Fig. 3). In the Elbe catchment there was a large proportion of people who were insured against flood damage—in fact 49.5% in group A and 49.9% in group B, in contrast to only 17.8% in group C. This has historical reasons: flood loss compensation was generally included in the household insurance in the former GDR (German Democratic Republic) of which Saxony and Saxony-Anhalt were part. Many people in eastern Germany still have similar contracts. In the rest of Germany, except for Baden-Württemberg, flood insurance is not widespread (Thieken et al., 2006b).

Acquisition of information, i.e. by gathering advisory information about flood precaution or by participating in (neighbourhood or flood) networks, was more popular than precaution by flood-proofing or building retrofitting (Fig. 3). Acquisition of information and particularly flood-proofing measures were undertaken to a higher percentage in the Danube catchment. The most frequently performed measures were flood-adapted interior arrangement and furnishing of storeys at risk, flood-adapted building use and the purchase of water barriers (Fig. 3). In general, the level of precaution dropped sharply if only flood-proofing or retrofitting measures were considered: The percentage of households that had undertaken at least one of these precautionary actions before August 2002 decreased to 21.0% in the Elbe group, to 28.2% at the Elbe tributaries and to 39.6% in the Danube catchment. This is alarming since only flood-proofing or retrofitting measures significantly reduce flood damage (see ICPR, 2002; Kreibich et al., 2005a).

Moreover, the people surveyed in the Elbe catchment evaluated the effectiveness of private precautionary measures lower than those in the Danube catchment. On a scale from 1 (= private precautionary measures can reduce flood damage very effectively) to 6 (= private precautionary measures are totally ineffective for flood damage reduction), 31.1% of the households interviewed in the River Elbe region and 36.1% from the Elbe tributaries gave a score of "1" or "2", whereas, in the Danube catchment, this percentage increased to 50.6%. Furthermore, the interviewees in group C estimated a higher probability of being affected by future floods than those in the Elbe catchment (A and B): on a scale from 1 (= it is very unlikely that I will be affected by future floods) to 6 (= it is very likely that I will be affected by future floods), only 18.5% in group A (Elbe) and 22.8% in group B (Elbe tributaries) chose a rank of "5" or "6", while 40.8% in group C (Danube catchment) gave this answer.

A correlation analysis was performed to investigate which factors influenced precautionary behaviour. For flood insurance, no coefficient was higher than 0.16. However, in group C in particular, acquisition of information was positively correlated with experience of floods, knowledge about the flood hazard and the perceived risk of future floods (Table 3).

In all three regions, flood-proofing and retrofitting of buildings was significantly correlated with the acquisition of information about self-protection. Further, the ownership of a flat or building was important for flood-proofing of the building in group B, as was flood experience in group C (Table 3).

Tab. 3: Rank correlation (Spearman's rho) between precautionary behaviour (BEFORE the flood event) and other parameters; only coefficients significant at the 0.05 level and ≥0.2 are shown.

Item (see Table 1 for units and labels)	Acquisition of information about precaution BEFORE the flood			Flood-proofing and retrofitting BEFORE the flood		
	A	B	C	A	B	C
Ownership structure					0.26	
Experience of floods			0.28			0.30
Knowledge about flood hazard	0.23		0.28			
Perceived risk of future floods			0.20			
Acquisition of information (BEFORE)	1.00	1.00	1.00	0.24	0.32	0.51

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

Tab. 4: Relationship between experience of floods, knowledge about the flood hazard and precautionary behaviour (only flood-proofing measures or retrofitting).

Sub-group description		A	B	C
Residents with experience of floods	Proportion in group	9.5%	20.2%	41.9%
	thereof: precautionary behaviour	23.0%	38.2%	54.8%
Residents without experience of floods, but with knowledge about the flood hazard	Proportion in group	31.6%	20.4%	17.4%
	thereof: precautionary behaviour	25.7%	33.1%	37.2%
Residents without experience of floods or knowledge about the flood hazard	Proportion in group	58.2%	59.3%	40.1%
	thereof: precautionary behaviour	17.7%	23.3%	25.0%

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

Precaution in the Danube catchment refers more clearly to experience of floods or to the knowledge of being at risk than in the other two regions. People with experience of floods showed more precautionary behaviour (54.8%) than people without experience of floods, but with knowledge about being at risk (37.2%), and much more than people without experience of floods and without knowledge of being at risk (25%). In all three sub-groups, the percentage of people who undertook some flood-proofing action is the highest in group C and the lowest in group A (Table 4).

The overall level of precaution is comparable to that in an investigation in Illinois, USA (Brenniman, 1994), where 68% of the respondents had spent some money on some kind of flood precaution. However, a correlation between precautionary behaviour and socio-economic variables is not noticeable in our data.

The regional differences in precautionary behaviour in the three areas can best be explained by the differences in experience of floods and the historical circumstances, rather than by the wider spread of flood insurance in Saxony and Saxony-Anhalt. Thieken et al. (2006b) showed that there is no significant difference in precautionary behaviour between insured and uninsured households in the Elbe catchment. Experience of floods seems to be the most important motivation for gathering information about private precautions. Precaution by flood-proofing and retrofitting of buildings relies on the extent of the acquisition of such information and to a lesser degree on experience of floods. Since the simple knowledge about the flood hazard also stimulates people to inform themselves about precaution—in the case of the Elbe region it is as effective as experience of floods (Table 4)—the publication of flood hazard maps is an important part of flood risk management. However, the dissemination of hazard maps should be accompanied by information material about possible precautionary actions. The material should be prepared for different groups, i.e. building/flat owners and tenants.

3.3 Response to the August 2002 flood

Flood warning Flood warnings disseminated by the authorities reached more than 40% of all surveyed people (Table 5). These warnings were spread mainly by loudspeakers, sirens, flyers or posters, followed by local radio stations (data not shown). One third of the people became aware of the danger of flooding by their own observation. Nationwide news and warning by neighbours, friends or relatives each contributed about 13%. However, more than a quarter of the people were not warned at all (Table 5).

According to the Mann-Kendall U test, flood warning differed significantly between all three regions with respect to the warning source and information, lead time and the people's knowledge of how to protect themselves and their property. While the percentage of people who were not warned at all is about 11% in group A, this figure rose to 28.5% in group C and even 42% in group B (Table 5). Furthermore, warnings were disseminated in large parts of region B and region C only a few hours before the houses were flooded, whilst, along the River Elbe, a lead time of several days was achieved (Table 5). The different lead times are explained by the different hydrological boundary conditions, e.g. the fast response of the mountainous catchments in region B.

Warnings from the authorities were investigated in more detail. Warnings in the Danube catchment included information about the maximum water level and the time–to-peak water level, as well as advice for damage mitigation, more often than in the other two regions, where considerably more information about evacuation was disseminated (Table 6). The information content was the worst along the Elbe tributaries: more than 17% of the warnings contained no detailed information about the flood and possible mitigation measures (Table 6). An indicator that assessed the most reliable warning source (ranging from 0: no warning to 4: warning by local authorities) and an indicator that summarised the warning information as introduced by Thieken et al. (2005) were further used in this paper.

Tab. 5: Answers to the question: "How did you become aware of the danger of flooding?"; given in percentage of all interviewed people per region (multiple answers possible) and average lead time per data group.

	A	B	C	Total
Flood warning by authorities	63.4%	23.2%	31.6%	40.5%
Own observation	29.7%	34.8%	36.5%	33.4%
Nationwide news	23.0%	6.9%	10.5%	13.9%
Warning by neighbours, friends etc.	14.7%	9.4%	16.5%	13.3%
Warning and evacuation at the same time	2.2%	1.1%	0.0%	1.2%
Other warning sources	0.5%	0.2%	0.4%	0.4%
No warning received	11.0%	42.0%	28.5%	26.8%
Not specified / no answer	0.8%	0.8%	0.4%	0.7%
Number of relevant interviews	639	609	449	1697
Average lead time (h)	65	11	17	37
Number of relevant interviews	464	284	257	1005

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

Tab. 6: Information content of official flood warnings (multiple answers possible).

	A	B	C	Total
Residential areas at risk	60.3%	50.8%	53.3%	57.0%
Advice on damage reduction	33.4%	32.6%	43.3%	35.1%
Maximum water level	29.9%	20.5%	57.5%	33.1%
Time-to-peak water level	22.5%	17.4%	46.7%	26.0%
Information about evacuation	30.6%	18.2%	0.8%	22.6%
Other useful information (levee breaches, streets etc.)	2.8%	2.3%	0.0%	2.2%
None of this information	8.4%	17.4%	8.3%	10.2%
Not specified / no answer	4.8%	6.1%	6.7%	5.4%
Number of relevant interviews (i.e. people warned by authorities)	395	132	120	647

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

Tab. 7: Reasons why people did not perform emergency measures (multiple answers possible).

	A	B	C	Total
It was too late to do anything	60.3%	72.1%	59.6%	65.1%
Nobody was at home	17.6%	18.0%	19.1%	18.3%
I thought emergency measures wouldn't be necessary	10.3%	6.6%	10.6%	8.8%
I did not think the flood would become so severe	5.9%	2.5%	8.5%	5.3%
I did not know what to do	2.9%	2.5%	5.3%	3.5%
I was not capable of doing anything	8.8%	1.6%	0.0%	2.8%
I thought emergency measures would be useless	2.9%	0.0%	4.3%	2.1%
Others	2.9%	1.6%	1.1%	1.8%
Not specified / no answer	1.5%	4.1%	3.2%	3.2%
Number of relevant interviews	68	122	94	284

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

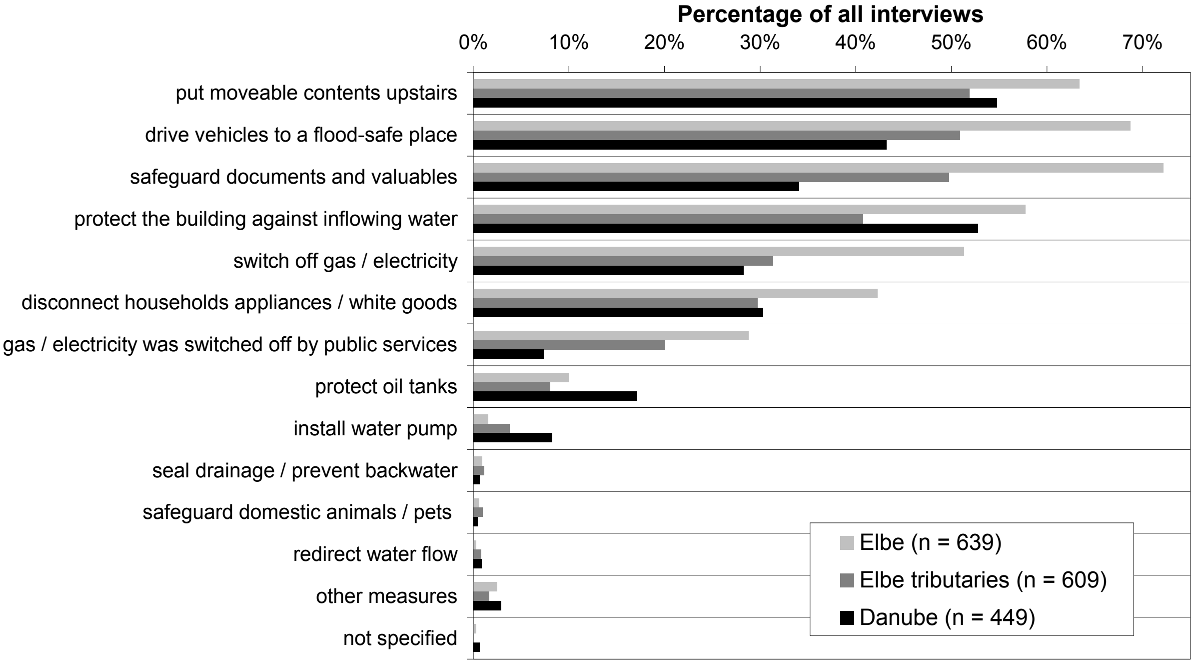

Fig. 4: Emergency measures performed (in descending order), as a percentage of all interviewed people per group (multiple answers possible).

The broad information content of warnings in the Danube catchment supported people’s knowledge about how to protect themselves and their households against the flood. On a scale from 1 (= I knew exactly what to do) to 6 (= I had no idea what to do), 43% of the people in group C chose “1” or “2”, while in the groups A and B this percentage dropped to 24.4 and 25.4%, respectively. Nonetheless, 21% (94 interviews) of all people interviewed in region C did not undertake any emergency measures, while this amounted to only 11% in region A (68 interviews), but 20% in region B (122 interviews). This might be due to the dominance of fast-onset floods in the Danube catchment, as well as to the fact that the flood happened during the summer holiday season. Accordingly, the main reason why people did not perform emergency measures was lack of time, followed by the fact that people were not at home (on vacation, business trips, etc.; see Table 7).

Of the people along the River Elbe (A) who did not carry out emergency measures, 30% had not been warned. This applied to 58% along the Elbe tributaries (B) and 57% in the Danube catchment (C). Forty-two percent of the interviewees in group A, 64% in group B and 47% in group C affirmed that they could have done more if they had been warned earlier. This confirms that official flood warnings are an important pre-condition for the performance of emergency measures. The highest potential for further damage reduction is in mountainous regions; however, flood warning in such areas is difficult.

Emergency measures Emergency measures that were undertaken by more than 50% of all respondents were safeguarding of movable household contents, vehicles, documents and valuables, as well as protecting the building against inflowing water. Figure 4 reveals that there was a higher percentage of people in group A who accomplished measures for their own safety (e.g. switching off electricity or gas). In contrast, in group C, there was a larger proportion of people who performed actions that were aimed at keeping the water out of the building, e.g. by installing barriers or water pumps. Moreover, oil tanks were protected more often in this group (Fig. 4). This might be explained by the experience during the Whitsun-flood in May 1999, where severe damage was caused by oil (Müller, 2000). Furthermore, the proportion of buildings that are heated with oil was much higher in the Danube catchment (53% of the interviews) than in the other two groups (16%).

Whether emergency measures can reduce flood damage also depends on their effectiveness. People who accomplished emergency measures were asked to evaluate the effectiveness of each activity on a scale from 1 (= very effective) to 6 (= totally ineffective). Figure 5 illustrates the effectiveness as an average rank per measure in the three areas of interest. Actions such as safeguarding important documents and valuables, as well as switching off electricity and gas, were easy and effective to perform, whereas it was more difficult to make effective arrangements for safeguarding household contents, or for the protection of the building. Figure 5 highlights that the latter measures were more effective in the Danube catchment, where people had more experience of floods and where water levels were not as high as in the other two groups (see below).

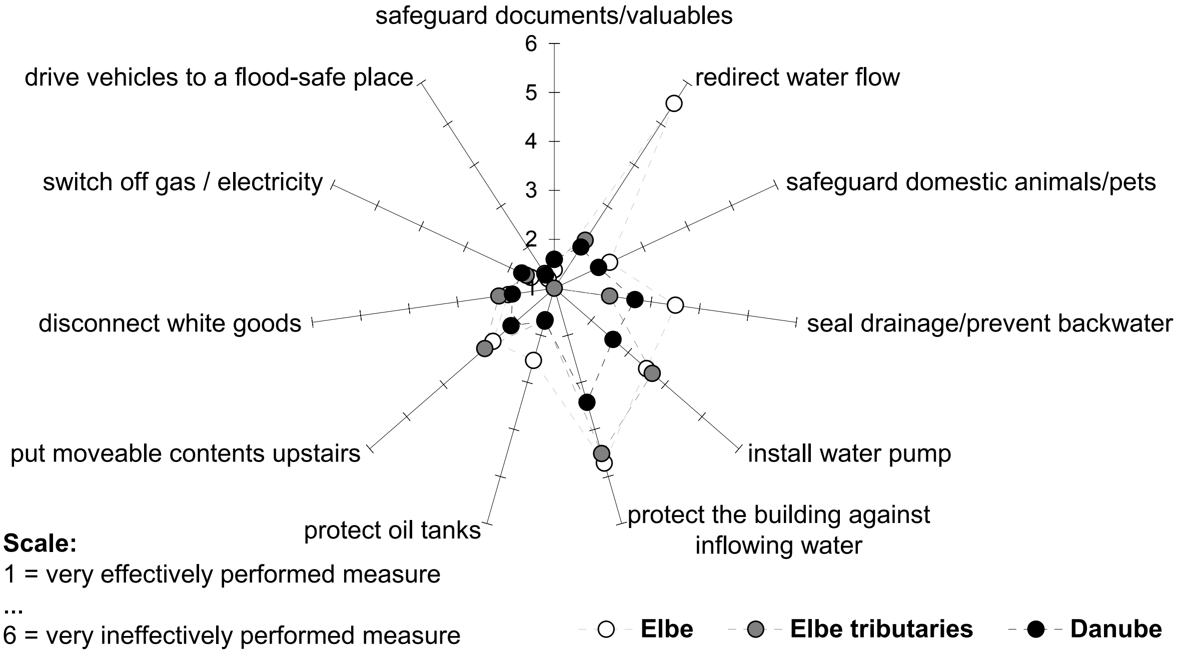

Fig. 5: Average effectiveness of emergency measures as evaluated by the people interviewed on a scale from 1 (= measure was very effective) to 6 (= measure was very ineffective).

Tab. 8: Rank correlation (Spearman's rho) between effectively performed emergency measures (indicator) and other parameters; only coefficients significant at the 0.05 level and ≥0.2 are shown.

Item (see Table 1 for units and labels)	A	B	C
Household size		0.20	
Ownership structure		0.23	
Knowledge about flood hazard			0.23
Flood water level		–0.24	
Flood duration		–0.20	0.20
Warning source			0.31
Warning information			0.23
Lead time	0.22	0.28	0.38
Perceived knowledge about self-protection			–0.22
Time spent on emergency measures	0.38	0.47	0.24
Number of people involved in emergency measures	0.20	0.24	0.25

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

For an overall assessment of the emergency measures, the following indicator was calculated: each measure performed received seven points from which the respective rank for efficiency was subtracted. Further, the individual measures were weighted in relation to their damage reducing effect (see Thieken et al., 2005). Table 8 shows how this indicator correlates with other parameters.

In all three regions, the time that was spent on emergency measures, the lead time and the number of people involved in emergency measures were positively correlated to emergency measures, i.e. the more time and people were available to take action, the more successful were emergency measures. Additional factors were determined in group B: here, the household size and the ownership of the house influenced emergency measures positively, whereas the flood impact in terms of water level and duration hampered the effectiveness of emergency measures. In group C (Danube catchment), the indicators for the flood warning source and information, as well as the knowledge about being at risk, showed considerable correlation with the overall indicator for emergency measures (Table 8). Only the perceived knowledge about how to protect against floods had a negative correlation coefficient, i.e. the more people knew (= rank 1), the better they succeeded in performing emergency measures effectively. Socio-economic variables, such as household characteristics, age, education, net income etc., influenced the performance of emergency measures only slightly (coefficients were smaller than 0.2, though significant). However, there was a tendency that younger people or people with better education and higher incomes were more capable of performing effective emergency measures, whereas households with elderly people had more difficulties (data not shown).

The analysis shows that flood warnings are an important pre-condition for the performance of emergency measures. However, their effectiveness is better in an area where people have more knowledge about self-protection, e.g. where flood warnings contained detailed information about the hazard in terms of water levels and time to peak flow, as well as information on appropriate actions. Besides warning characteristics, the number of people available to take action also determines the success of emergency measures. Efforts to improve early warning systems, especially in mountainous regions, should be done with regard to longer lead times, but also with regard to the warning content. Only if people know how to react in the case of flooding, how high the water levels will be and how much time they have in which to react, can damage be prevented or reduced to a considerable degree.

3.4 Flood damage and recovery

Adverse effects of the flood In 1273 of the 1697 surveyed households, respondents specified the cost of damage to household contents and 1079 the cost of building damage, in terms of repair and replacement. The mean damage amounted to €16 335 and €42 093, respectively (cf. Table 9). Losses significantly differed between the three data groups: the damage to household contents and particularly to buildings was the highest in group A, followed by group B. The cost of damage in group C was considerably lower (Table 9). In all regions, the cost of damage was correlated with other adverse effects, such as duration of evacuation and cleaning-up (Table 9).

In addition, Table 9 reveals which parameters most influenced the amount of financial loss. Damage to household contents was particularly influenced by the flood water level, the contamination of the flood water and, in the groups A and B, by the ownership structure, whereas in group C the credibility of the warning was more important. Damage to buildings was also considerably influenced by the water level and the contamination of the flood water, followed by the knowledge about the flood hazard in group A and the flow velocity in the groups B and C (Table 9).

In the groups A and B, emergency measures as well as flood-proofing and retrofitting of buildings were negatively correlated to damage to buildings indicating the potential to reduce flood damage by private precautions also during extreme events. This was analysed in detail by Kreibich et al. (2005a). More details about the relationship of several parameters to flood damage are given in Thieken et al. (2005).

Recovery After the August 2002 flood, the German government launched an emergency fund for reconstruction (Sonderfond Aufbauhilfe) of €7100 million. Furthermore, money from the European Union (€444 million), donations (€350 million) and insurance compensation (€1800 million) were available for loss compensation and enabled a rapid recovery (Mechler and Weichselgartner, 2003; Schwarze and Wagner, 2004; DZI, 2004).

In our survey, people were asked to compare the state of their household contents and their building before the flood and at the time of the interview, and to evaluate the difference on a scale from 1 (= household contents/buildings are already replaced/ restored completely) to 6 (= there is still considerable damage to household contents/to the building). At the time of interview, i.e. about 8–9 months after the flood, 31.5% of the people in group A evaluated the building status with "1" or "2", i.e. had already recovered well. For the household contents this share increased to 56.0%. In group B, recovery was a little faster: 46.9% reported a good recovery of the building, 60.6% a good recovery of the household contents. Recovery was at best in group C: more than 60% evaluated their recovery with "1" or "2" for both building and content damage.

Besides the characteristics of the flood (water level, flood duration and contamination), the amount of damage had the highest correlation with the level of recovery in all three data groups (Table 10). This is further illustrated by Fig. 6: recovery decreases with an increasing median of building damage.

Tab. 9: Mean flood damage and rank correlations (Spearman's rho) between flood damage and other parameters; only coefficients significant at the 0.05 level and ≥0.2 are shown.

Item (see Table 1 for units and labels)	Damage to household contents			Damage to residential building		
	A	B	C	A	B	C
Mean damage (€)	20 770	13 088	13 536	57 829	45 824	16 834
Duration of evacuation	0.49	0.43	0.24	0.33	0.48	0.20
Duration of cleaning-up **7**	0.44	0.37	0.35	0.28	0.45	0.45
Ownership structure	0.52	0.32			–0.23	
Perceived quality of household contents	–0.21		–0.21			
Knowledge about flood hazard				0.20		
Perceived efficiency of private precaution	0.24				0.23	
Flood-proofing / retrofitting (BEFORE)					–0.30	
Flood water level	0.47	0.47	0.50	0.53	0.66	0.52
Flood duration	0.26				0.23	
Flow velocity			0.22		0.31	0.25
Contamination of the flood water	0.28	0.30	0.33	0.30	0.43	0.32
Perceived credibility of the warning			0.31			
Overall assessment of emergency measures				-0.20	–0.26	

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

Tab. 10: Rank correlation (Spearman's rho) between recovery and other parameters; only coefficients significant at 0.05 level and ≥0.2 are shown.

Item (see Table 1 for units and labels)	Perceived level of replacement of damaged contents			Perceived level of repair of damaged building		
	A	B	C	A	B	C
Flood water level			0.23		0.31	0.23
Flood duration			0.20	0.20		0.23
Contamination of the flood water				0.25	0.24	
Perceived credibility of the warning		0.27				
Perceived knowledge about self-protection					0.24	
Perceived efficiency of private precaution					0.20	0.21
Duration of evacuation						0.23
Duration of cleaning-up					0.23	
Damage to household contents	0.25	0.26	0.30	0.20	0.27	0.21
Damage to building	0.26	0.27	0.29	0.25	0.43	0.32
Received loss compensation					0.25	

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

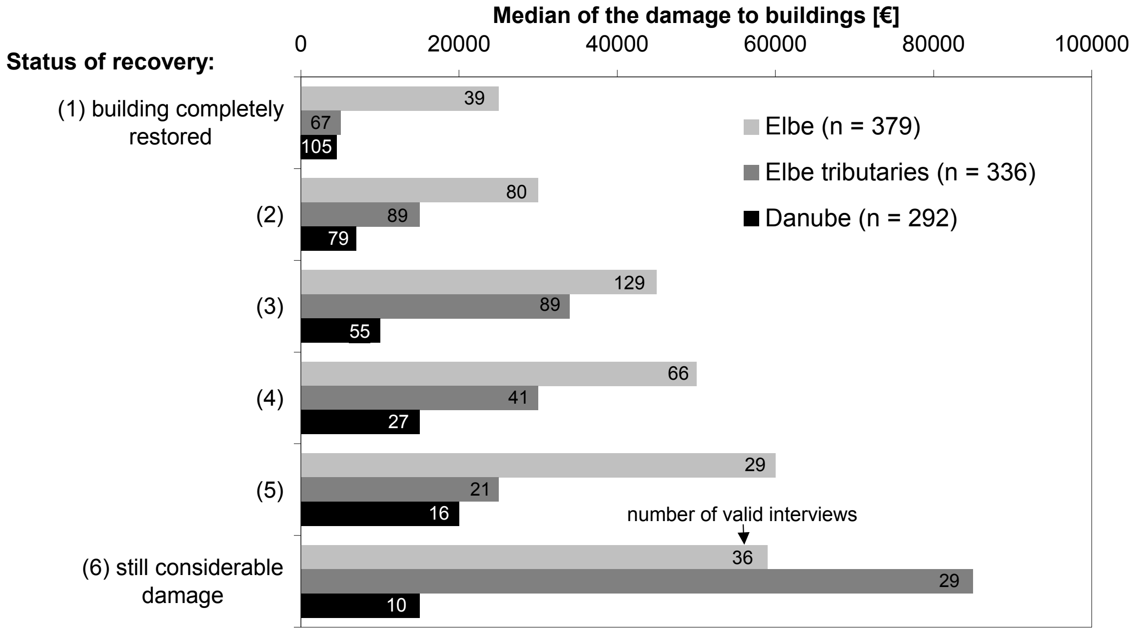

Fig. 6: Relationship between the status of recovery at the time of the interview (evaluated on a scale from 1 to 6) and the median of the building damage.

Moreover, knowledge about self-protection and perceived efficiency of private precautions were also advantageous for fast recovery, e.g. slow recovery was connected to a lack of knowledge about self-protection in group B. This demonstrates that recovery is affected not only by the degree of flood impact, but also by people's preparedness and their knowledge about flood mitigation.

3.5 Lessons learned: will people be better prepared for future floods?

The interviewees were also questioned whether they undertook any precautionary measures after the flood and whether they were planning to undertake some within the next six months. The extent of the acquisition of information about precaution and of flood-proofing and retrofitting of buildings, as well as the number of insured households, increased enormously. For some precautionary actions, the percentage of involved households nearly doubled (Fig. 3). In total, only about 4% of all households interviewed had not undertaken, or were not planning to undertake, any precautionary action. However, the differences between the three regions outlined in Section 3.2 remained. Flood insurance is still more important in the Elbe catchment, i.e. in the regions A and B (Fig. 3), whereas people in the Danube catchment (region C) concentrate more on building retrofitting, particularly on flood-adapted building use and furnishing, building sealing and the purchase of water barriers (Fig. 3).

Table 11 shows what influenced the different kinds of precautionary action. In data group A (River Elbe) no significant correlation higher than 0.16 was found. All kinds of precautions tended to correlate with the age of the interviewee (the younger they were, the more precautions were taken), and the household size, i.e. particularly young families seem to invest in flood insurance and flood-proofing or retrofitting measures (data not shown since correlation coefficients were lower than 0.20). In group B, building owners were more willing to invest in building retrofitting, as were people who believe that private precautions are effective (Table 11). In group C, the amount of damage and the compensation for loss were important for flood-proofing and retrofitting of buildings. Moreover, people who had not been affected by floods before, or who did not know enough about the hazard and about self-protection, informed themselves about precautions after the flood and were also willing to flood-proof their buildings (Table 11).

About 3% of all households interviewed wanted to avoid flooding in the future and decided to move to a flood-safe area. Table 11 reveals that this option was particularly considered by those who were tenants.

To further improve the level of precautions and to motivate people to invest in flood-proofing measures, it seems to be important to provide information about the options for precautions that can be taken. In particular, after a flood event, there is a window of opportunity for initiating precautionary measures. In order to convince people, the effectiveness of private precautionary actions, i.e. the potential damage reduction, should gain more attention in the discussion of flood risk management. Besides providing different recommendations for homeowners and tenants, special information for elderly people might also be necessary.

Tab. 11: Rank correlation (Spearman's rho) between the changes in precautionary behaviour after 2002 and other parameters; only coefficients significant at the 0.05 level and ≥0.2 are shown.

Item (see Table 1 for units and labels)	Change in flood insurance			Change in acquisition of information on precaution			Change in flood-proofing and retrofitting			Moving to a flood-safe area		
	A	B	C	A	B	C	A	B	C	A	B	C
Ownership structure								0.22		-0.24	-0.21	-0.22
Experience of floods						-0.20						
Knowledge about flood hazard						-0.20						
Perceived efficiency of private precaution								-0.20				
Perceived knowledge about self-protection			0.23			0.21			0.31			
Damage to building									0.21			
Received loss compensation									0.22			
Change in acquisition of information on precaution			0.20	1	1	1		0.20	0.30			

Data groups: A: River Elbe, B: Elbe tributaries, C: Danube catchment.

4 RECOMMENDATIONS AND CONCLUSIONS

The analysis of how preparedness, response and recovery of residents in three different regions in Germany are correlated to socio-economic variables, experience with previous floods and flood impact of the event in 2002 leads us to the following recommendations:

The pure knowledge of living in a flood-prone area stimulates the acquisition of information about self-protection. However, this does not necessarily lead to flood-proofing or retrofitting measures. Therefore, more information is needed about the effectiveness and the cost-benefit-ratios of different precautionary measures. Further, specific information, e.g. different information leaflets with flood mitigation options for different groups of people, would be helpful. Tenants, homeowners, elderly people or large households all have different abilities to perform precautionary and emergency measures. Therefore, information about private precautions has to meet people’s interests and capabilities in order to convince them that they will be able to reduce their potential flood damage significantly.

Despite the potential to mitigate flood losses, the flood impact, particularly the water level and the contamination of the flood water, affect the cost of damage and degree of recovery to a great extent. Therefore, financial precautions, i.e. flood insurance, should be strongly recommended especially in areas with a low insurance cover.

People’s knowledge about the flood hazard and about self-protection as well as good warning information help people to better perform emergency measures. Therefore, flood warnings should be released with more detailed information about expected water levels, time to peak flows and recommendations for appropriate response. However, the time and the number of people available to undertake emergency measures are the most important factors during the response phase. Therefore, longer lead times of early warnings are needed, especially in mountainous regions. Further, it would be worthwhile to think about improved response capacities in flood situations, e.g. by activating neighbourhood help or disaster management assistance.

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References can be found at the end of the thesis.

Paper 11: Insurability and mitigation of flood losses in private households in Germany

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Abstract

In Germany, flood insurance is provided by private insurers as a supplement to building or contents insurance. This paper presents the results of a survey of insurance companies with regard to eligibility conditions for flood insurance, changes after August 2002, when a severe flood caused 1.8 billion euro of insured losses in the Elbe and the Danube catchment areas, and the general role of insurance in flood risk management in Germany. Besides insurance coverage, governmental funding and public donations played an important role in loss compensation after the August 2002 flood. Therefore, this paper also analyses flood loss compensation, risk awareness and mitigation in insured and uninsured private households. Insured households received loss compensation earlier. They also showed slightly better risk awareness and mitigation strategies. Appropriate incentives should be combined with flood insurance in order to strengthen future private flood loss mitigation. However, there is some evidence that the surveyed insurance companies do little to encourage precautionary measures. To overcome this problem, flood hazards and mitigation strategies should be better communicated to both insurance companies and property owners.

Keywords: Elbe flood, damage compensation, insurance, natural hazards, precautionary measures

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1 INTRODUCTION

A severe flood event struck Germany, Austria, the Czech Republic and Slovakia in August 2002 in the catchment areas of the Elbe and the Danube. In Germany, 21 people were killed and substantial parts of the infrastructure were destroyed. The most affected German state was Saxony, where the total flood damage estimate had risen to 8.7 billion euro by December 2003 (SSK, 2004). Saxony was followed by Saxony-Anhalt with 1.2 billion euro in damages (IKSE, 2004). Meanwhile, total losses in Germany were estimated to have been 11.6 billion euro, of which 1.8 billion euro were covered by insurance. The figure of 15% insured loss is rather low in comparison to other flood events in Germany (see Kron, 2004). This may be due to the enormous damage to infrastructure. Only 45% of the losses were sustained in the private sector (Kron, 2004).

The economic losses from August 2002 exceed losses caused by other natural disasters in Germany by far. Therefore, many administrative and legislative projects were launched to improve flood risk management (see DKKV, 2003). Immediately after the flood, the German government launched an emergency relief fund of 500 million euro and a reconstruction aid fund of 7.1 billion euro (*Sonderfonds Aufbauhilfe*). Furthermore, money from the European Union Solidarity Fund (444 million euro), public donations (350 million euro) and insurance compensation (1.8 billion euro) were available for loss compensation (Mechler and Weichselgartner, 2003; Schwarze and Wagner, 2004; DZI, 2004). In comparison to natural disasters in other industrialised countries, such as the Kobe earthquake in 1995, as well as to other flood events in Germany, governmental assistance, amounting to more than 60% of all losses, is very high for the August 2002 flood (Mechler and Weichselgartner, 2003). An analysis of seven earthquakes and floods that occurred in the 1990s revealed that on average only 45% of total disaster losses were compensated by governmental aid and insurance together (Linneroth-Bayer et al., 2001). For example, during the severe flood in the catchment area of the Rhine river in 1993 (total losses of 530 million euro, of which 160 million euro were insured losses), only 10% of the losses were compensated by governmental assistance and about 60% of the losses remain uncompensated (Linneroth-Bayer et al., 2001).

Governmental disaster assistance is often criticised as an ineffective and insecure way of dealing with flood losses (Anderson, 2000; von Ungern-Sternberg, 2003, Schwarze and Wagner, 2004). Since government aid (in Germany) is not based on formal legislation, it depends, for example, on the extent of the disaster or the media coverage. Thus, affected persons cannot rely on this kind of compensation. Insurance coverage, however, provides a right of compensation agreed upon by contract (e.g. compensation for building damage, cleanup costs) and loss compensation is reliable and fast (Platt, 1999; Kron 2004; FEMA, 2004). Moreover, governmental disaster assistance is commonly financed by (additional) taxes and can thus weaken overall economic development due to a reduction in purchasing power and the government's limited ability to invest (von Ungern-Sternberg, 2003).

Flood insurance is available in several countries including Germany, but conditions and concepts are very different. Various systems have been compared e.g. by Swiss Re (1998), Barraque (2000), Graff (2001), Vetters and Prettenthaler (2003) and von Ungern-Sternberg (2004).

The most difficult problem is antiselection: Insurance coverage is mostly requested by people in flood-prone areas who are frequently affected by floods, whereas people in low or residual risk areas are not interested in flood insurance coverage. Thus, the basic principle of pooling of risks is violated. This problem is tackled by different approaches ranging from non-provision of insurance coverage (e.g. in the Netherlands), governmental disaster loss funds with a fixed pay-out amount per year (e.g. in Finland), (restrictive) private insurance (e.g. in Germany or the United Kingdom), private insurance in combination with a state reinsurance (e.g. in France), to compulsory building insurance for all building owners (e.g. in most cantons of Switzerland and in Spain) (Swiss Re, 1998; Barraque, 2000; Vetters and Prettenthaler, 2003). In the latter case, insurance coverage is provided by (state) monopoly insurance institutions, which have the advantage of low advertising and administration costs in comparison to competitive private insurance companies (von Ungern-Sternberg, 2004). In addition, such an insurance system can be better combined with land use planning and flood loss mitigation. Swiss building insurers, for example, spend a considerable amount of the premiums, about 15%, on mitigation (von Ungern-Sternberg, 2004). However, private insurance companies also publish guidelines on flood loss reduction (e.g. ABI, 2004).

The combination of flood insurance with land use planning and damage mitigation was also an important concept in the US National Flood Insurance Program (NFIP), which is – in contrast to the Swiss and Spanish systems – a voluntary insurance for most building owners and partly subsidised by the state. The NFIP is well documented and its success and reforms have been critically analysed (e.g. Richman, 1993; Platt, 1999; Anderson, 2000; Burby, 2001; Chivers and Flores, 2002; FEMA, 2002).

The NFIP was launched in the USA in 1968. In its framework, flood-hazard zones and the degree of flood risk were identified, criteria for construction in floodplains were established and risk-based flood insurance premium rates were set (Burby, 2001). The flood insurance rate maps, showing all the areas that would be inundated by a 100-year flood, are not merely guidelines; the mapped flood-prone areas and the flood elevation data are legally binding (Platt, 1999). The maps are relevant for flood insurance premiums as well as for damage mitigation, since the NFIP focuses on flood loss prevention up to the 100-year flood level. Thus, the lowest floor (including the basement) of new constructions has to be elevated to the level of the 100-year flood.

At the beginning of the NFIP, it was assumed that additional costs for flood insurance premiums and for fulfilling hazard mitigation requirements would make settlements in floodplains uneconomic (US Congress, 1966b in Burby, 2001). However, 30 years of rising flood losses have led to the conclusion that the NFIP could not stem the tide of extensive development in high-risk areas (Burby, 2001). Some authors even suggest that flood insurance has allowed, if not encouraged development in floodplains (see Arnell, 1987; Richman, 1993; Platt, 1999). On the other hand, the NFIP has contributed to considerably reduced susceptibility of new structures to flood impacts: buildings erected before 1975 have suffered approximately six times more flood damage than buildings which meet the NFIP mitigation requirements (Pasterick, 1998 in Burby, 2001).

White and Etkin (1997) concluded that a proactive campaign to strengthen the demand for mitigation measures would be an essential next step in attenuating the increase in disaster losses attributable to societal changes such as increasing population density, growing economies (more consumption and accumulation of goods), urbanisation and concentration of people in high-risk coastal areas, as well as to climate change. In theory, public agencies, insurers as well as property owners, contractors and developers should be interested in mitigation measures, particularly in cost-effective measures. These are measures for which the discounted expected benefits over the life of the property are greater than the upfront investment expenses and other costs (Kleindorfer and Kunreuther, 1999). However, few property owners voluntarily adopt mitigation measures. Investigations in the USA revealed that less than 15% of building owners have taken action to flood proof or retrofit their building (see Burby, 2001 for further references; Blanchard-Boehm et al., 2001). It may be that people do not believe that investments in (long-term) risk reduction measures will increase their residence's property value, or they may have short time horizons and/or severe budget constraints (Kleindorfer and Kunreuther, 1999). However, several surveys among flood-affected private households in Britain have shown that there is no evidence that flood insurance discourages emergency actions (Arnell, 1987).

Some authors discuss concrete actions that insurers and governments might undertake to encourage mitigation measures. Kleindorfer and Kunreuther (1999) demonstrated that both insurers and property owners could benefit from mitigation even if it was to be rewarded by lower deductibles. However, if insurance was to serve as an effective tool for reducing future losses due to natural disasters it needed to be linked to well-enforced building codes (Kunreuther, 1996; Kleindorfer and Kunreuther, 1999; Kunreuther, 2001). Building codes mandate that property owners adopt mitigation measures. To encourage their adoption, Kleindorfer and Kunreuther (1999) suggested a certificate of disaster resistance for each structure that met or exceeded building code standards. Such a certificate would enable financial institutions, contractors and insurers to offer various incentives, e.g. low-interest loans, reduced deductibles, premiums or taxes (Kleindorfer and Kunreuther, 1999; Kunreuther, 2001). Insurers may also want to limit coverage only to those structures that are given a certificate of disaster resistance (Kunreuther, 2001).

Germany is one of the few European countries in which private insurance companies have offered natural hazards insurance as a supplement to contents or building insurance (Vetters and Prettenthaler, 2003). So far, little is known about the terms of insurance in Germany, how insurance companies reward mitigation strategies of residents and how they are involved in flood risk management as a whole. Moreover, it is unclear how flood insurance coverage influences risk awareness and loss mitigation strategies in private households. Therefore, this paper addresses the following research questions:

- What are the terms for natural hazards insurance in Germany? What changes occurred after the August 2002 flood?
- How many people had insurance cover during the August 2002 flood and how did this affect their loss compensation in comparison to uninsured households?
- How does insurance coverage influence flood risk awareness and loss mitigation in private households?
- How do insurance companies support flood risk reduction and mitigation and how are they involved in overall flood risk management?

2 DATA AND METHODOLOGY

Two surveys were undertaken to answer the above-mentioned questions. A standardised questionnaire was mailed to 119 insurance companies. The questionnaire was comprised of 30 questions, utilising mainly checklists providing the opportunity for open-ended answers. The following topics were addressed:

- characteristics of the insurance company: insurance products relevant to losses due to natural disasters, year of launch, types of perils covered, percentage contribution of natural hazards insurance premiums to total turnover of the company,
- flood risk analysis: flood hazard assessment of households applying for insurance, general and special conditions which have to be fulfilled to obtain insurance coverage (distinguishing between insurance on building and contents, as well as the situation before and after the 2002 flood), information given to the insured about the hazard zone they are living in, general information given to the insured or brochures regarding flood loss mitigation, existence, type and range of deductibles, kinds of loss mitigation measures that are rewarded by the insurer and types of rewards, amount and return interval of loss accumulation of the company,
- losses due to the August 2002 flood: percentage of the insured who were affected by the flood, status of surveying losses, completion date of loss compensation, mitigation measures that effectively reduced damage, kind types of losses frequently claimed, total and average loss compensation,
- consequences of the flood event in 2002: kinds of changes in insurance conditions (distinguishing between existing and new insurance contracts), change in demand and number of contract conclusions after August 2002,
- the role of insurers in flood risk management: general involvement of the insurance industry in different fields of flood risk management (assessment on a rank scale from 1 = insurance should play a decisive role to 6 = insurance should not participate), general issues where insurance companies require more influence, attitude towards compulsory natural hazards insurance.

The response rate to the questionnaire was 21% (i.e. 25 of 119 insurance companies). 60% of the insurance companies who returned the questionnaire (15 of 25 companies) had been affected by the 2002 flood. 20 companies (17%) gave written or verbal notice that they would not participate in the survey. The main reasons for non-participation were that the survey was considered to be outside the scope of insurers or that the Association of German Insurers (GDV) was regarded to be responsible (12 cases). Therefore, an interview with a representative from the GDV was carried out based on the questionnaire (referred to as GDV, pers. comm. 2003). Other reasons for non-participation were lack of available manpower to complete the survey (one case) or the topic was considered to be too explosive (one case). Six companies did not state any particular reason for non-participation.

Additionally, private households were questioned about the damage to their buildings and household contents due to the flood event in August 2002 as well as about factors that may have influenced the damage. Computer-aided telephone interviews were carried out by the SOKO-Institute, Bielefeld, Germany, in April and May 2003. In total, 1248 flood-affected households were interviewed in the Elbe catchment area in Saxony and Saxony-Anhalt. The person who had the most knowledge about the flood event in the household was always questioned. Tenants were only asked about their household contents and related losses. To complete the interview the building owner was also called and asked about the building and flood-related damage to it. On average, an interview lasted 30 minutes. The interview consisted of approximately 180 questions addressing various topics. In this paper, only questions addressing insurance coverage, mitigation measures undertaken before and after the flood, emergency measures undertaken during the flood, flood risk awareness, flood experience and absolute losses are analysed. For more details and results of the survey see Kreibich et al. (2005a) and Thieken et al. (2005).

3 RESULTS AND DISCUSSION

3.1 General conditions of natural hazards insurance in Germany and its market penetration

In Germany, private insurance companies have provided natural hazards insurance as a supplement to building or contents insurance since 1991. This supplemental contract covers losses due to floods, torrential rain, earthquakes, land subsidence, avalanches and snow build-up. By default, losses due to windstorms and fires are covered by any building insurance policy. Losses due to storm surges are an uninsurable risk in Germany (GDV, pers. comm. 2003). Our survey among insurers revealed that 70% of the companies also provide coverage for losses due to backwater in storm-water drainage systems, whereas losses caused by a rise in groundwater level are only covered by two companies.

Market penetration Building insurance, which covers windstorm and fire losses, has a widespread market penetration of 90% in Germany (GDV, pers. comm. 2003), since banks usually demand it to secure loans (Schwarze and Wagner, 2004). This does not apply to the above-mentioned supplemental coverage for other natural hazards. In most parts of Germany its current market penetration is estimated to be approximately 10% for household contents and 4% for residential buildings (GDV, pers. comm. 2003). However, there are two regions with a higher insurance density: Baden-Wuerttemberg and the territory of the former German Democratic Republic (GDR). Flood loss compensation was generally included in mandatory building insurance in Baden-Wuerttemberg until 1994. Due to EU regulations this monopoly insurance had to be abandoned. Currently, more than 80% of the property owners in Baden-Wuerttemberg still have flood insurance coverage (Kron, 2004). Flood loss coverage was also provided by the household insurance in the former GDR, which Saxony and Saxony-Anhalt were part of. 30 to 50% of the people in the new German states (former GDR) still have comparable contracts (Mechler and Weichselgartner, 2003; Kron, 2004). In our survey of affected private households in Saxony and Saxony-Anhalt about half of the interviewed people (49.5%) in the Elbe catchment area were insured against flood damage in August 2002 (Fig. 1).

The flood hazard zoning system ZÜRS and insurability Particularly hazard-prone buildings are often excluded from flood insurance or are only insured if high premiums are paid. The premise for a transparent rating is a consistent hazard zoning system. Since national flood hazard maps do not exist in Germany, a countrywide zoning system for inundation (ZÜRS) was developed for insurance purposes, lead-managed by the GDV. In the first version of ZÜRS, launched in 2001, three hazard zones with different probabilities of inundation (Table 1) were identified for 55,000 km of river reaches (Kriebisch, 2000, Kleeberg, 2001). After the August 2002 flood, a fourth zone corresponding to the 200-year flood was introduced. Table 1 shows the insurability of buildings in the different zones. Buildings in the high-risk zone, where flooding occurs on average at least once in 10 years, are generally not insurable. Buildings in the zones with moderate and low risk are insurable if enough accumulation cover exists. Buildings with a very low inundation risk are always insurable. The introduction of the fourth zone and the enhanced control of risk accumulation will probably lead to a significant increase in the non-insurable area (currently 10%) (Schwarze and Wagner, 2004).

The survey among insurers revealed that, in addition to the ZÜRS-zoning, the number of preceding flood losses and the distance to the water bodies play a crucial role in risk assessment (Table 2). Table 2 also illustrates that after the 2002 flood risk assessment has been carried out more precisely, particularly by a more widespread use of ZÜRS.

In general, an insurance application is allowed if the insured object is situated in the old ZÜRS-zone I and if no previous damage has occurred in the past 10 years (Table 3). If the criteria in Table 3 are not met, then only about 30% of the surveyed insurers grant insurance coverage with special conditions, among which are a raised insurance premium (4 entries), a raised deductible (4 entries) and/or building upgrading and retrofitting (3 entries).

In general, conditions of existing insurance contracts will not be altered after the flood in 2002. However, when new contracts are signed, one third of the surveyed companies have announced an increase in insurance premiums and/or deductibles. More than 50% of the companies signalised that they would improve their risk assessment.

Altogether, the survey indicates that natural hazards insurance is routine business. The terms are established in a uniform procedure with little room for negotiation. After the August 2002 flood, more efforts have been put into risk assessment and the conditions have been tightened slightly.

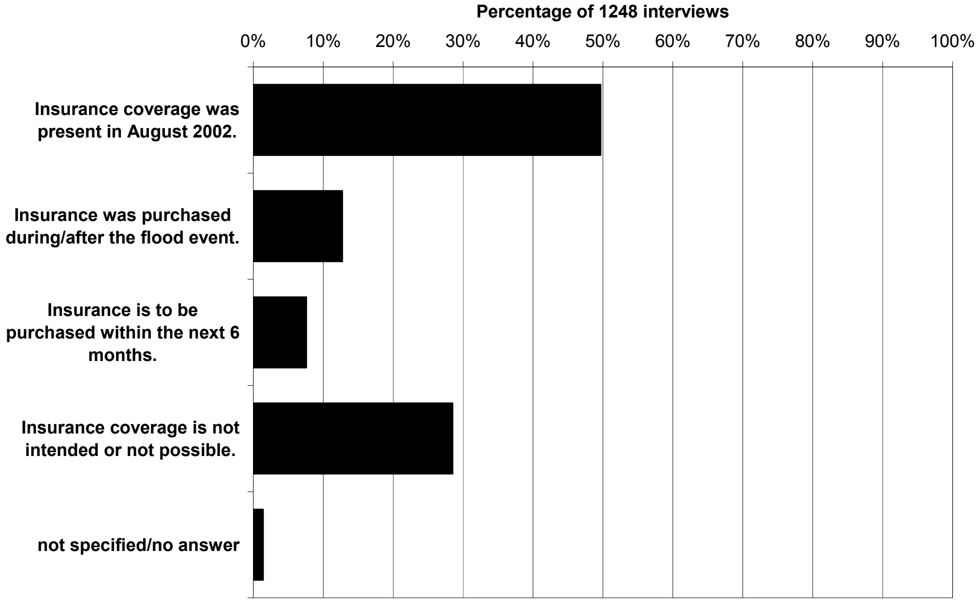

Fig. 1: Flood insurance coverage in 1248 private households affected by the August 2002 flood in Saxony and Saxony-Anhalt (Data source: survey of affected private households).

Tab. 1: ZÜRS flood hazard zones and insurability (modified from Kron, 2003).

Zone (old)	Zone (new)	Hazard	Average statistical return period of being inundated	Current insurability
I	I	very low	at maximum once in 200 years	fully given
I	II	low	once in 50 to 200 years	basically given
II	III	moderate	once in 10 to 50 years	basically given
III	IV	high	at least once in 10 years	generally not given

Tab. 2: Evaluation criteria for the assessment of the flood risk of residential buildings in the context of natural hazards insurance (data: survey of direct insurers).

Criteria	before the 2002 flood [number of answers]	after the 2002 flood [number of answers]
number of flood losses in the past 5 to 10 years	18	18
horizontal distance to the water bodies	14	15
hazard assessment according to ZÜRS	13	18
vertical distance to the water bodies / slope of the land surface	11	12
assessment of each individual case	10	9
distance to upstream dams etc.	6	6
type of building construction	5	4
susceptibility of the assets to be insured	1	1
questionnaire with regard to insurance location and previous losses	1	1
precautionary measures (if previous losses)	1	1
valid answers	18	19

Tab. 3: Conditions that usually have to be fulfilled to acquire natural hazards insurance coverage for residential buildings (data: survey among direct insurers).

Criteria	before the 2002 flood [number of answers]	after the 2002 flood [number of answers]
no previous damage in the past 5 years	17	18
no previous damage in the past 10 years	16	17
ZÜRS-Zone I (old zoning, i.e. return period of inundation > 50 years)	11	15
ZÜRS-Zone II (old zoning, i.e. return period of inundation between 10 and 50 years)	6	7
at maximum one previous damage in the past 10 years	2	2
Others	3	5
valid answers	19	20

3.2 Flood loss compensation and recovery of insured and uninsured private households following the August 2002 flood

Since nearly 50% of the interviewed private households were insured in August 2002 (cf. Fig. 1), the survey provided a good database for the comparison of insured and uninsured households. As mentioned above, a vast sum of governmental money was available as compensation for 2002 flood losses.

At the time of the interviews in April and May 2003, i.e. 8 months after the flood, loss compensation was not fully completed. In the survey of insurers, some companies estimated that damage regulation would be finished by the end of 2003. Uninsured households could apply for governmental reconstruction aid until the end of May 2003. The source of compensation money (e.g. government funds, donations or insurance compensation) was not collected in our survey. Thus, a definitive assessment of the differences in loss compensation between insured and uninsured households cannot be made here. However, the results suggest a trend.

Flood loss compensation In general, the survey revealed a high variability in loss compensation among the affected households. However, at the time of the interviews, the mean flood loss compensation was substantially higher in insured households (Table 4).

Tab. 4: Comparison of total flood loss compensation (contents and buildings) in insured and uninsured private households (data source: survey among private households).

Percentage of private households …receiving loss compensation of	... with insurance (n = 424)	... without insurance (n = 389)
at least 50%	67.5%	32.1%
at least 80%	37.5%	15.4%
100%	25.9%	10.3%

Tab. 5: Comparison of insured and uninsured private households with regard to flood impact, flood losses during the August 2002 flood, loss compensation by April/May 2003, flood experience, risk awareness and loss mitigation (Data source: survey among private households). Significance was tested with the Mann-Whitney-U-Test.

	with flood insurance	**no flood insurance**	**Signi-ficance**
Damage			
Mean building damage	52,276 €	52,001 €	no
Mean damage to household contents	17,440 €	16,779 €	< 0.05
Recovery			
Mean loss compensation	23,749 €	12,540 €	< 0.01
Mean satisfaction with loss compensation (scale from 1 to 6)	2.01	2.44	< 0.01
Mean recovery from building damage assessed on a scale from 1 to 6	2.94	3.07	no
Mean recovery from household content damage assessed on a scale from 1 to 6	2.40	2.57	no
Flood experience and risk awareness			
Mean number of experienced previous floods	0.47	0.28	< 0.01
Percentage of people without flood experience, but with knowledge about the flood hazard	36%	26%	< 0.01
Assessment of being affected by future floods (scale from 1 to 6)	3.30	3.29	no
Mitigation			
Mean indicator for acquiring relevant information BEFORE August 2002	0.62	0.41	< 0.01
Mean indicator for building mitigation measures BEFORE August 2002	0.53	0.32	< 0.01
Assessment of the effectiveness of private mitigation measures on a scale from 1 to 6	3.33	3.24	no
Mean indicator for performing emergency measures	38.24	36.58	no
Mean time spent on emergency measures [h]	20.52	22.28	no
Flood impact			
Mean flood water level (above ground) [cm]	94.98	97.77	no
Mean flood duration [h]	184.48	177.05	no
Mean indicator for flood contamination	1.59	1.5	no

Table 5 compares insured and uninsured households with regard to flood impact, flood losses during the August 2002 flood, loss compensation, flood experience, risk awareness and loss mitigation. Whereas no significant differences in building damage occurred, there was slightly more damage to household contents in insured households.

At the time of the interviews satisfaction with flood loss compensation was higher in insured households: on a scale from 1 to 6, where 1 means "I was very satisfied with the flood loss compensation" and 6 "I was not at all satisfied with the flood loss compensation", 75% of the insured interviewees were very satisfied, i.e. they chose a "1" or "2" on the rank scale. This percentage dropped to 60% in the uninsured households. The following reasons for dissatisfaction were most frequently mentioned: insufficient loss compensation, excessive waiting and processing times, overly complicated and bureaucratic handling of the claims, as well as delay or denial of payment.

Recovery The affected persons were asked to compare the state of their household contents and buildings before the flood and at the time of the interview, and to evaluate the difference on a rank scale from 1 (= household contents/buildings are already completely replaced/restored) to 6 (= there is still considerable damage to household contents/to the building). Approximately eight months after the flood, 42.1% of the insured persons evaluated building status with a "1" or "2", i.e. had already recovered well. For household contents this figure increased to 61.0%. A score of "5" or "6", indicating insufficient recovery, was given in 15.9% (buildings) and 10.5% (household contents) of the answers respectively. In uninsured households, only 35.0% evaluated their recovery with a "1" or "2" with regard to building damage and 55.5% with regard to damage to household contents. Only 14.9% (buildings), but 15.1% (household contents) of the interviewees in uninsured households gave a score of "5" or "6". Although the recovery in insured households was slightly better, the differences between the mean recovery in insured and uninsured households are not significant (Table 5).

Discussion All in all our analysis demonstrates that, despite extensive governmental disaster assistance after the August 2002 flood, insured private households were compensated earlier and most likely to a greater extent, and have thus recovered a little, but not significantly faster than uninsured households. Although intended by the government, there was no complete reconciliation of compensation paid by governmental agencies and insurance companies. Thus, the possibility cannot be ruled out, that some insured households also received money from the governmental emergency fund or that some were even compensated twice. The extent of overcompensation cannot be determined since the source of compensation money was not collected in this survey.

Despite the better compensation, 29% of the surveyed private households still did not intend to purchase insurance (Fig. 1). The increase in requests for natural hazards insurance right after the flood declined again after a couple of months (GDV, pers. comm. 2003).

3.3 Insurance coverage, risk awareness and mitigation measures

The survey of private households also provided a good database for comparing risk awareness and loss mitigation in insured and uninsured households. Since risk awareness and mitigation activities were expected to be influenced by flood experience, this aspect was analysed first. Among the surveyed insured households, 18% had experienced at least one previous flood, whereas this applied to only 12% of the uninsured households. People without flood experience also showed a significant difference in knowledge about the flood hazard of their residence (Table 5): 35% of the insured households without flood experience declared that they had known about their living in a flood-endangered area. This applied to only 26% of the uninsured households without flood experience. Both groups, however, estimated a similar probability of being affected by future floods (Table 5).

Loss mitigation measures before August 2002 It is often alleged that people with flood insurance do not attempt to prevent or mitigate flood damage. The survey among private households, however, indicated that the time spent performing emergency measures and the kinds of measures undertaken do not differ significantly between insured and uninsured households (Table 5). In the run-up to the August 2002 flood, insured households tended to be even better informed about mitigation and tended to flood proof their building more often than uninsured households (Table 5, Fig. 2). 48.5% of the insured households had acquired information regarding flood mitigation or participated in emergency networks, whereas only 33.9% of the uninsured households had done likewise. 28.5% of the insured households had performed at least one of the mitigation measures shown in Fig. 2, whereas this was true for only 20.5% of the uninsured households. Thus, all in all, the knowledge and willingness to engage in self-protecting behaviour were slightly better developed in insured households than in uninsured.

Mitigation measures undertaken after the August 2002 flood Although many households had performed mitigation measures in the aftermath of the flood, there was still a considerable percentage of people who did not intend to invest in mitigation in the future (see Kreibich et al., 2005a). This percentage was slightly higher in insured households, especially with regard to flood proofing the building (Fig. 3). 33.7% of the insured households and 31.2% of the uninsured households intended to perform none of the measures shown in Fig. 3. The percentage of people who did not regard private mitigation measures as an effective tool for flood loss reduction (i.e. they chose values from 4 to 6 on a rank scale from 1 to 6, where 1 means "private mitigation measures can reduce flood damage effectively" and 6 "private mitigation measures do not reduce flood damage effectively at all") was very similar in both groups (Table 5).

Discussion The question arises as to how people can be motivated to invest in loss mitigation. The possibilities, costs and expected benefits (in terms of reduced loss) of private mitigation measures should be better communicated to the public. Several German ministries have published information material to encourage people to undertake mitigation measures (BMVBW, 2002; MURL, 2000b; MUF, 1998). A few studies have even given quantitative information about flood loss reduction due to mitigation measures (FEMA, 1998; ICPR, 2002; Kreibich et al., 2005a). Average extra repair costs for using water resistant material or altering building use, and loss savings for a shallow and a deep floodwater level for measures for specific house types were determined by the Association of British Insurers (ABI) for a couple of typical houses (ABI, 2004). For some measures, like replacing floors and joists with treated timber to make them water resistant or moving the washing machine to the first floor, flood loss reduction already exceeds the extra repair costs if only one shallow flood (water level up to 5 cm) occurs (ABI, 2004). For definitive cost-benefit analyses, the specific situation and properties of the house must be taken into consideration, as set rules and generalisations may be misleading.

Jakli (2003) suggested that banks could also encourage insurance coverage and mitigation. After the 2002 flood it became evident that uninsured people with loans posed a financial risk to banks because their flood losses caused insolvency. Therefore, Jakli (2003) suggested that banks pay special attention to appropriate insurance coverage when customers apply for a loan. This could also be a way to strengthen land use regulation and building codes through insurance coverage and the granting of loans.

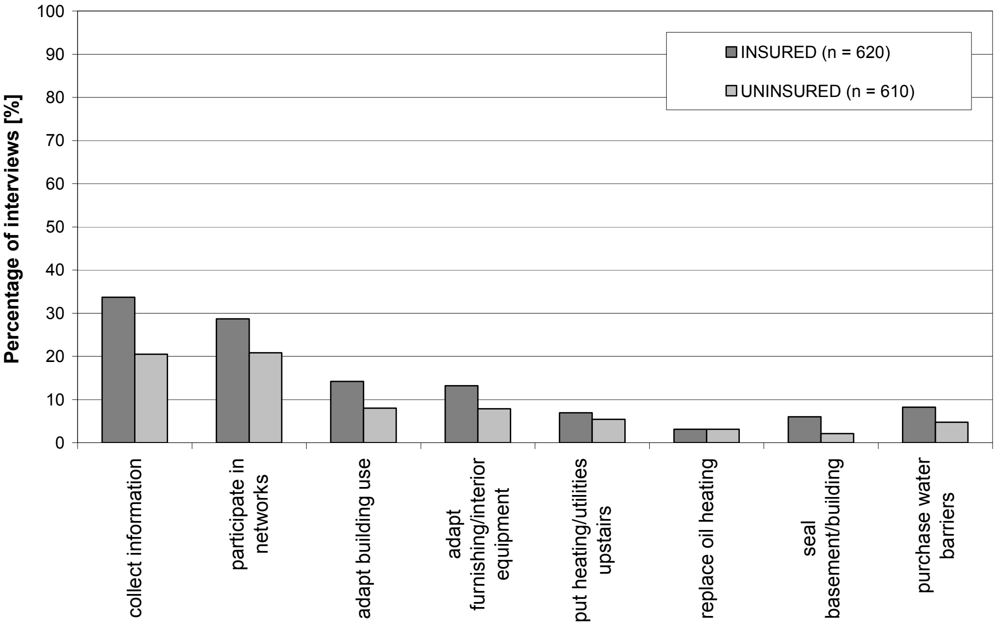

Fig. 2: Differences between insured and uninsured private households with regard to precautionary measures: implementation of mitigation measures BEFORE the flood event in August 2002 (data source: survey of private households).

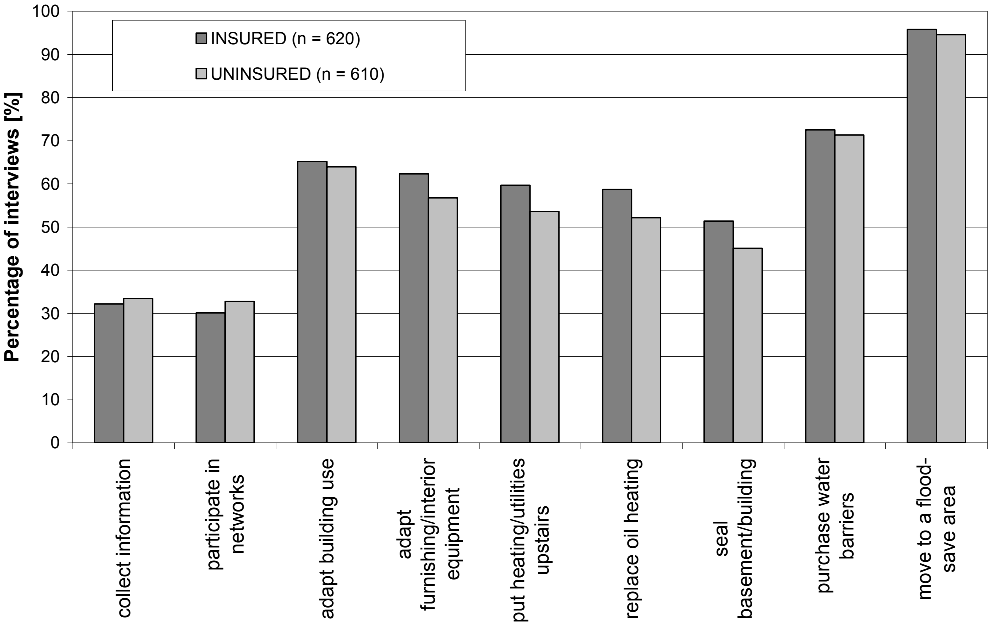

Fig. 3: Differences between insured and uninsured private households with regard to loss mitigation: percentages of households that did not intend to implement mitigation measures in the future (data source: survey of private households).

3.4 The role of insurance companies in flood risk management in Germany

In the framework of flood risk reduction, insurance coverage should be combined with loss mitigation measures.

A well-established instrument to encourage private loss mitigation in the context of insurance is the deductible: in case of a damaging event the insured has to pay for part of the damages himself and should consequently be interested in reducing future damage. Ideally, the deductible should be linked to the risk of the insured object so that particularly high-risk households have the strongest incentive to undertake mitigation measures. The survey among insurance companies revealed that all insurers charge a deductible, but none was linked to the flood hazard zones. Commonly, the deductible amounted to 10% of the total loss (true for 45% of valid answers concerning building insurance, 41% of valid answers concerning contents insurance), followed by a fixed percentage of 1% to 10% of the insured sum (true for 30% of valid answers concerning building insurance and 36% of valid answers concerning contents insurance) and a fixed deductible (true for 25% of valid answers concerning building insurance, 18% of valid answers concerning contents insurance). In most cases, the deductible for private households amounts to a minimum of 500 €, to prevent minor losses, and to a maximum of 5000 €.

Insurance companies could do even more to improve private mitigation activities. For example, they could encourage policyholders to reduce their susceptibility by informing them about flood-adapted building use and materials and about behaviour in case of a flood event, as well as by rewarding the implementation of building codes (see Introduction and Section 3.3). The survey of German insurers revealed that only 14% of the surveyed insurers rewarded voluntary private mitigation measures. For example, despite previous flood losses or ZÜRS-zone I or II, insurance coverage was allowed if the building was sealed, the basement used in a flood-adapted manner or if a locking device for the prevention of backwater was installed. In standard risk cases voluntary loss mitigation measures were not rewarded e.g. by lower premiums or lower deductibles.

On demand, 80% of the surveyed insurers informed building owners regarding which hazard zone they were living in. However, only 25% to 35% of the insurers gave advice on how to mitigate flood losses. None of the surveyed companies provided information material on flood loss reduction.

These results contradict the role in flood risk management to which the surveyed insurers credit themselves: the role of the insurance sector in the revision, implementation and advancement of technical standards for flood loss reduction as well as in the informing and advising of the insured was assessed relatively high (Fig. 4). However, Fig. 4 points out that the surveyed insurers are not really sympathetic towards active participation in land use regulation, precautionary measures for buildings and disaster response. A decisive role was only given to the promotion of the compilation of flood hazard maps in Germany, which can probably be explained by the successful development of the zoning system ZÜRS.

Discussion The inadequate promotion of flood loss mitigation by insurers is probably due to the fact that building and/or contents insurance belong to routine business, in which profits are relatively low. Therefore, expenses for consultancy, appraisal and control of mitigation measures are too high in comparison to premiums and profit margins. Further, if deductibles or premiums were to be reduced because loss mitigation measures were taken, the insurance companies would have to be sure that the products used work properly. This has prompted the GDV to establish a working group with the goal of certifying products for flood loss reduction (GDV, 2003, pers. comm.). In the United Kingdom, for example, such a certification scheme came into force in 2003. Some insurers have already indicated that buildings fitted with these certified products may be eligible for building insurance coverage on more favourable terms (Wordsworth and Bithell, 2004).

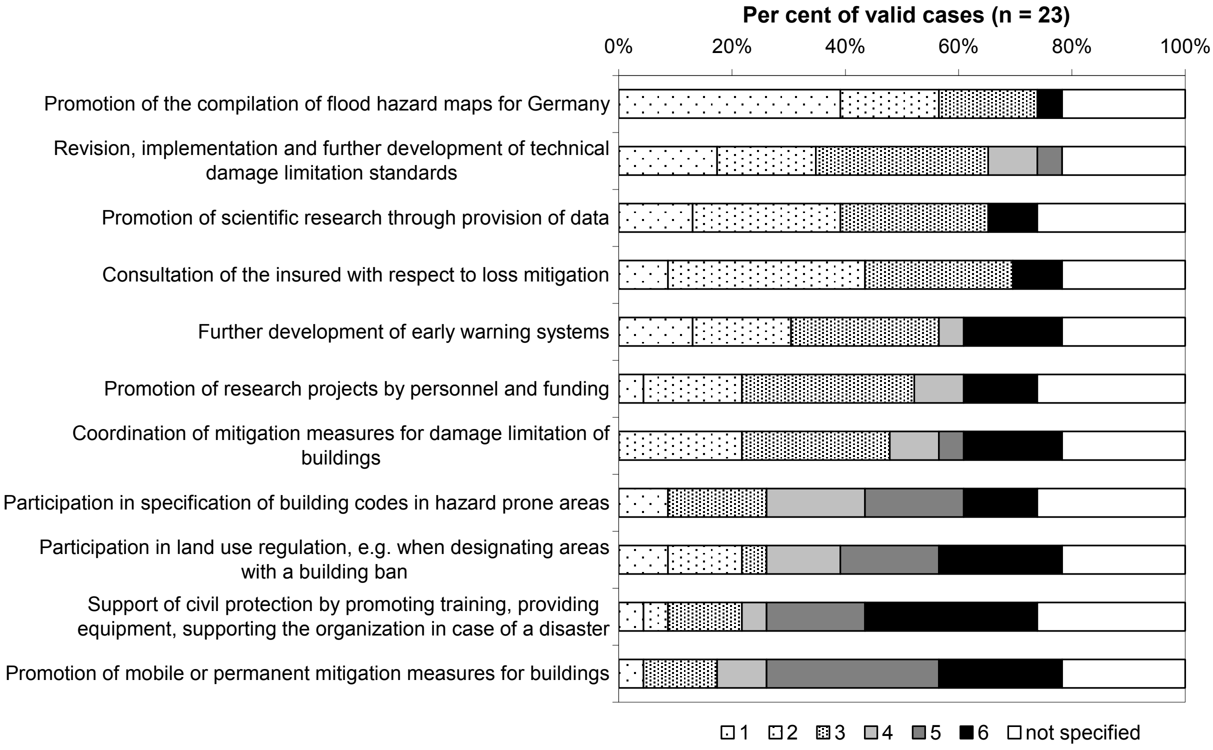

Fig. 4: Assessment of the future participation of insurance companies in flood risk management in Germany on a scale from 1 to 6, whereby 1 means “insurance should play a decisive role” and 6 means “insurance should not participate” (data: survey among insurers). Measures are sorted in decreasing order of average assessment rank.

It also became apparent in the survey that many insurers are not well informed about flood risks and possibilities for flood loss mitigation. The survey revealed that, in contrast to reinsurance companies, most of the insurers did not know the probable maximum accumulation loss (PML) of their portfolio.

After the flood in August 2002, the GDV calculated a PML for Germany with an assumed return period of 200 to 300 years that amounted to 10 to 15 billion euro for residential buildings only (GDV, pers. comm. 2003). These calculations were made as input for negotiations about compulsory natural hazards insurance (including high risk areas and losses due to storm surges, see Schwarze and Wagner, 2004). Although the insurance industry had generally given up their negative attitude towards a compulsory insurance, no final agreement could be reached between the insurance industry and the German states (*Deutsche Länder*).

4 CONCLUSIONS

Despite the availability of insurance covering damage due to natural disasters, government funding and public donations played an important role in the compensation of losses resulting from the August 2002 flood. The high level of governmental disaster assistance in 2002 has not really encouraged people to prepare themselves for future disasters. In addition, insurers barely reward mitigation measures in private households. Although it has to be acknowledged that many of the affected people invested in loss mitigation, our analysis shows that about one third of the interviewed affected households neither purchases insurance nor invests in loss mitigation. Thus, people seem to have little moral hazard. Since it is unclear how much governmental assistance will be given after future floods, this is alarming behaviour and calls for better communication regarding flood risks and (private) mitigation measures.

Furthermore, our analysis shows that, despite the high level of government financial support, insured households in the Elbe catchment area received loss compensation earlier. These households also showed a slightly better risk awareness and preparedness. A considerable share of insured households in the investigation area had voluntarily invested in mitigation measures. Mitigation seems to be related to flood experience or people's knowledge about their living in a flood-endangered area, since these variables also differ significantly between the surveyed insured and uninsured households. Thus, informing people about the flood hazard of their residence and possibilities for flood insurance and flood loss mitigation would be a first step in strengthening the disaster-preparedness of private households. In addition, insurance companies should acknowledge the mitigation activities of private households through incentives.

If building loans were coupled with appropriate insurance coverage and if insurance coverage was better combined with precautionary measures in building construction, a substantial reduction in flood risk would result.

Acknowledgements

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References can be found at the end of the thesis.

Paper 12: 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. Building precautionary measures had been actually undertaken by 67% of the households 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.

Keywords: Dresden, Elbe, Flood impact, Flood damage, Preparedness, Precautionary measures, Flood management

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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. 2006b). 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. 2005b). 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 km^2 of which the settlement area covers 38% (Fig. 1).

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 400–500 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).

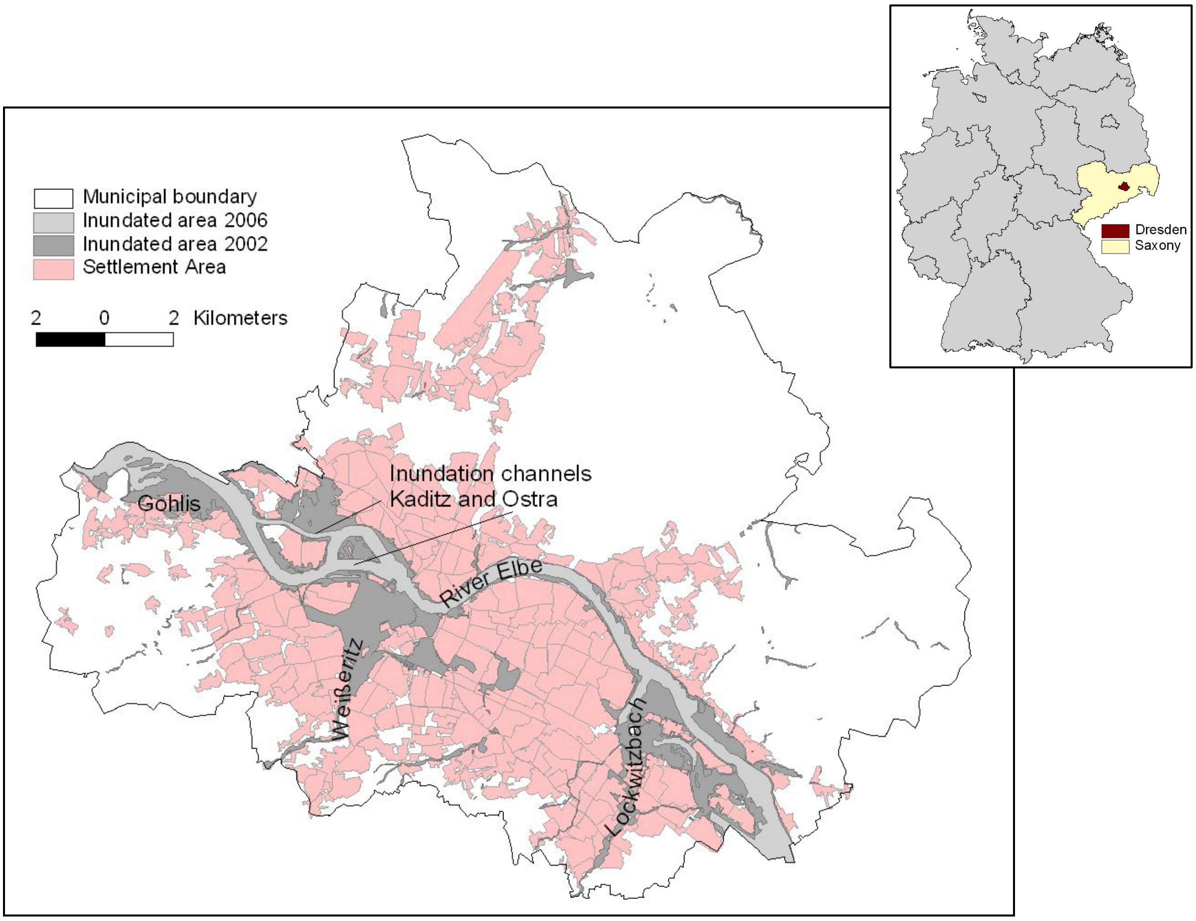

Fig. 1: Location of Dresden in Saxony, Germany. Inundated areas during the floods in 2002 and 2006. (Data sources: infas GEOdaten (2004): municipal boundary; _Bundesamt für Kartographie und Geodäsie (2003, 2004): Inundated area in 2002, ATKIS-Basis DLM; Sächsisches Landesamt für Umwelt und Geologie &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

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 springtime, if the thaw period is accompanied by high rainfall (Grünewald 2006). In 2005, such a warm, rainy period occurred only for 2 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 20th century, flood experience and preparedness are low (Kreibich et al. 2005a; Thieken et al. 2007). Flood experience is strongly linked to preparedness, e.g., for households to undertake private precautionary measures (Kreibich et al. 2005a; 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. 2005a). 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 article 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. 2005a; 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 1,697 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 do not 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. (2005a) 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 (Norusis 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 4,580 $m^3 s^{-1}$ and therefore considerably lower than in 1845, for which a reconstructed discharge of 5,700 $m^3 s^{-1}$ 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 2,500 $m^3 s^{-1}$ in the second half of the 20th century (Fig. 2).

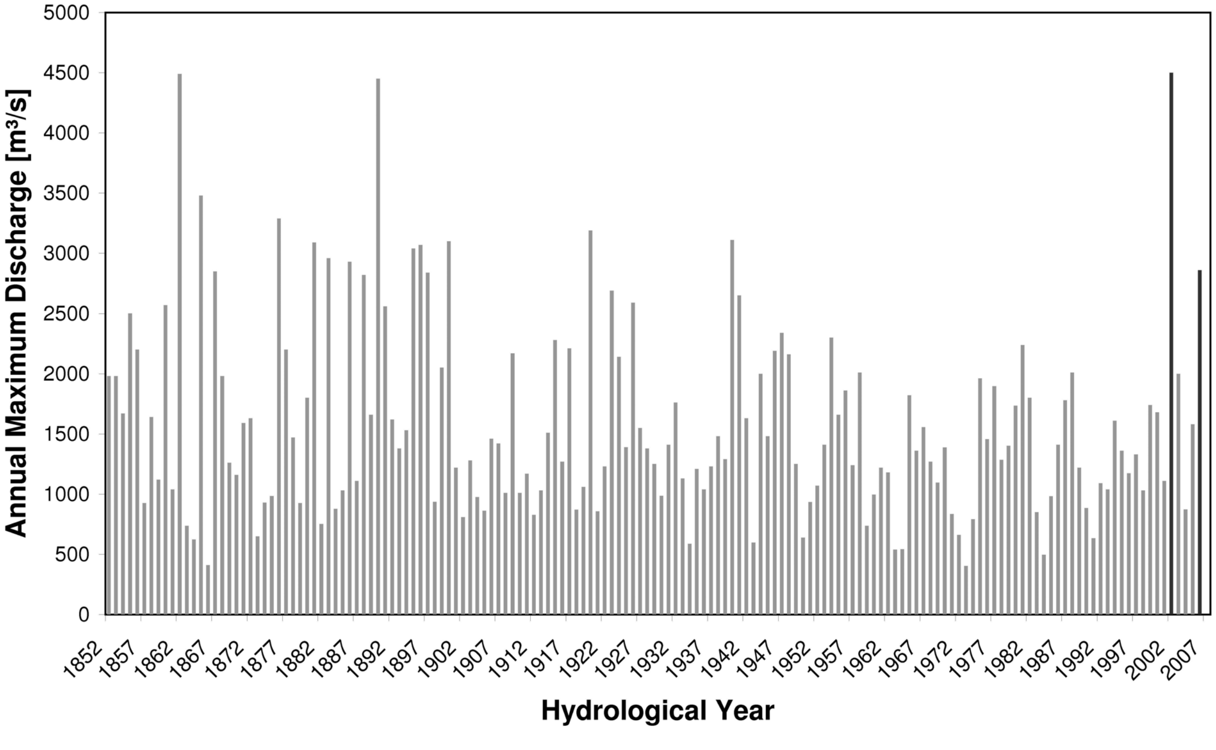

Fig. 2: Annual maximum series 1852–2006 at the Dresden gauge (data sources: GRDC Koblenz, WSA Dresden). The flood discharges in 2002 and 2006 are highlighted in black. The mean flood discharge of the AMS amounts to 1,591 $m^3 s^{-1}$.

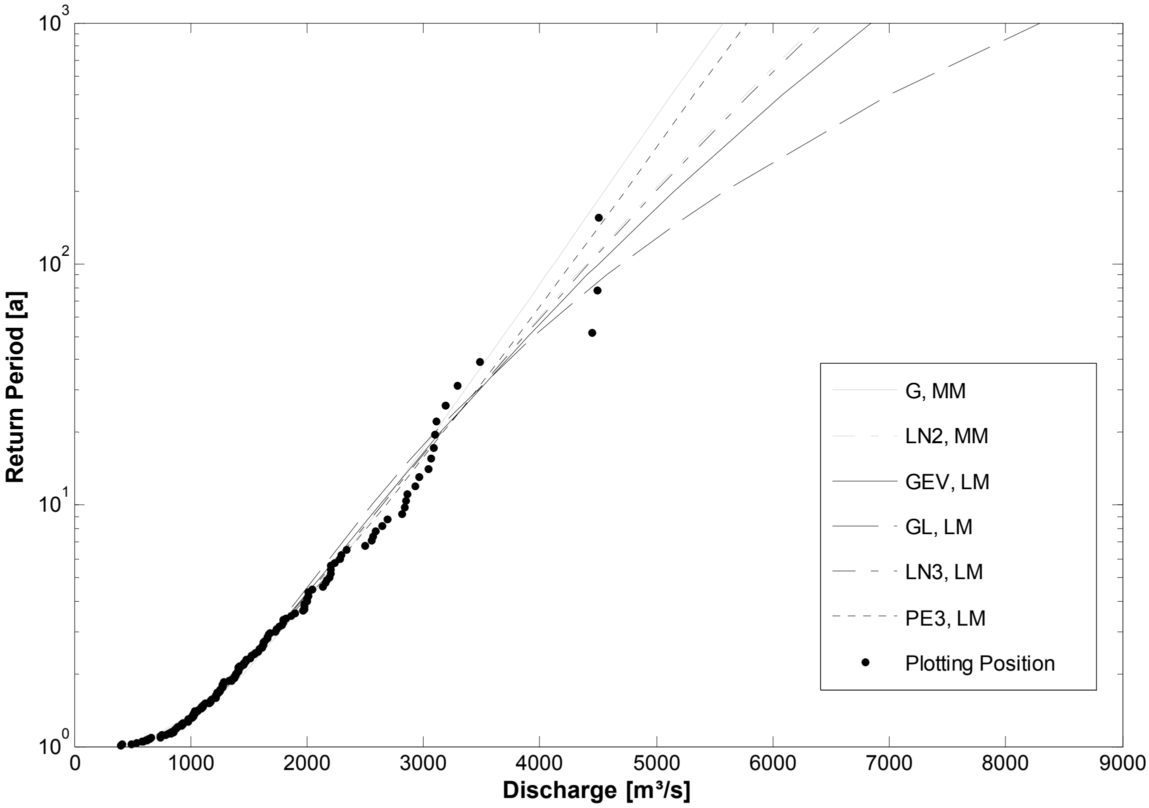

Fig. 3: Flood frequency analysis at the Dresden gauge based on the annual maximum series 1852–2006 (abbreviations: G: Gumbel, LN2: 2-parametric lognormal, GEV: generalised extreme value, GL: generalised logistic, LN3: 3-parametric lognormal, PE3: Pearson type III, MM: method of moments, LM: L-Moments).

Tab. 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

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 riverbed, assess the 2002 flood as a 1,000-year event and assume that the measured discharge of 4,580 $m^3 s^{-1}$ is the highest value ever occurred at Dresden (Pohl 2007). This underlines the severity of the flood in 2002.

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 (Korndörfer 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 5,700 $m^3 s^{-1}$ (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 1940ies (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. 2005b).

Flood plains have not 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 riverbed, 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 1990ies, 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-year 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. 2005a). 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).

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). In Dresden 43% of the households were insured against flood losses, which is for historical reasons considerably higher than the German average (Thieken et al. 2006b).

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. 2005a). 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. 2005a). 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).

Tab. 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).

	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%

Note: All shown parameters are significantly different on a 0.05 level between the two flood periods.

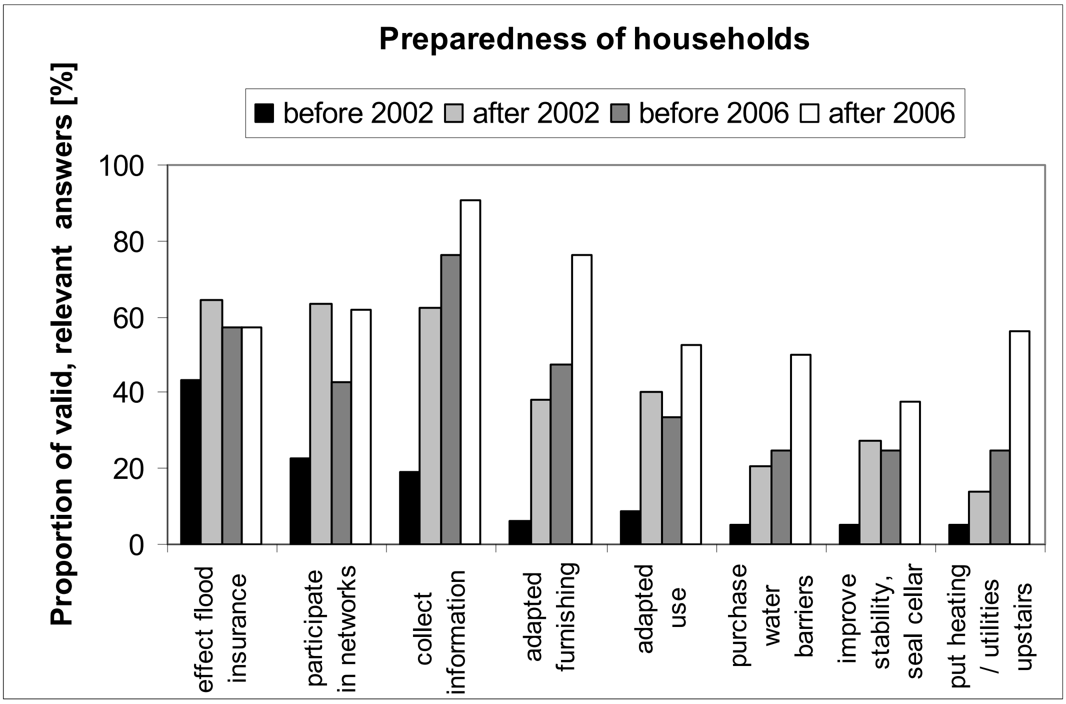

Fig. 4: Proportion of households in Dresden who had undertaken measures of precaution before and after the flood in 2002 (depending on the measure: n = 138–295) and before and after the flood in 2005/2006 (depending on the measure: n = 17-20). Only building owners were asked about improvements to the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

The general rise in preparedness that was observed after the flood in 2002 (including measures that were planned for the consecutive 6 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 2000b). 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. 2006b).

Generally, after 2005/2006, all measures, except for a flood-adapted building structure, have been undertaken by the majority of households (≥50%) (Fig. 4).

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).

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.

Tab. 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

Note: * Negative values indicate a water level below ground surface, affecting only the cellar

Tab. 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.

	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

Note: n = 133–250 depending on parameter and loss type.
Spearman-Rho (pair-wise data exclusion;
** correlation is significant on a 0.01-level;
* correlation is significant on a 0.05-level)

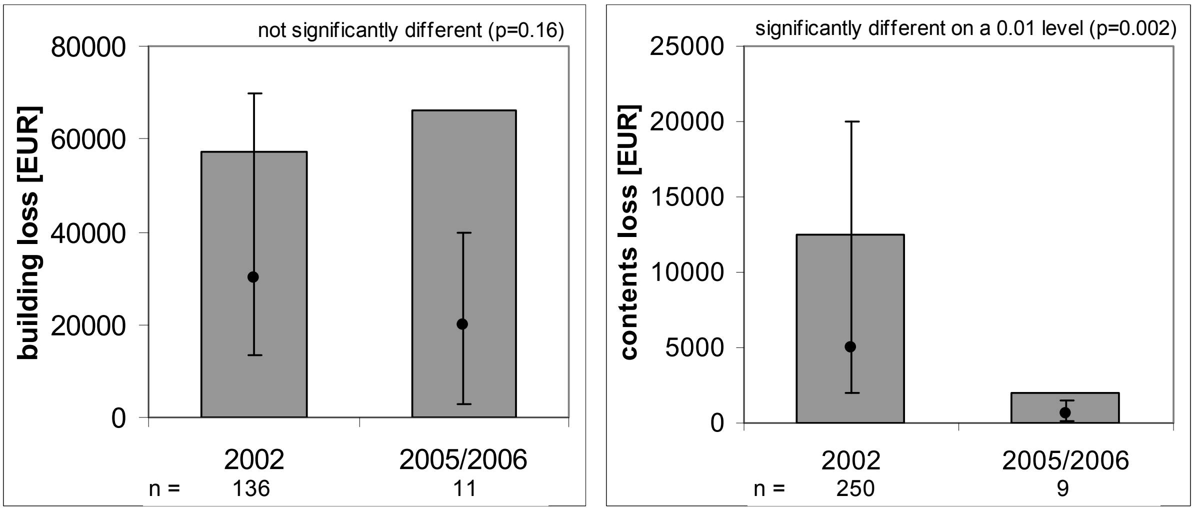

Fig. 5: Building and contents losses in 2002 and 2005/2006 in Dresden (bars = means, points = medians and 25–75 %-percentiles).

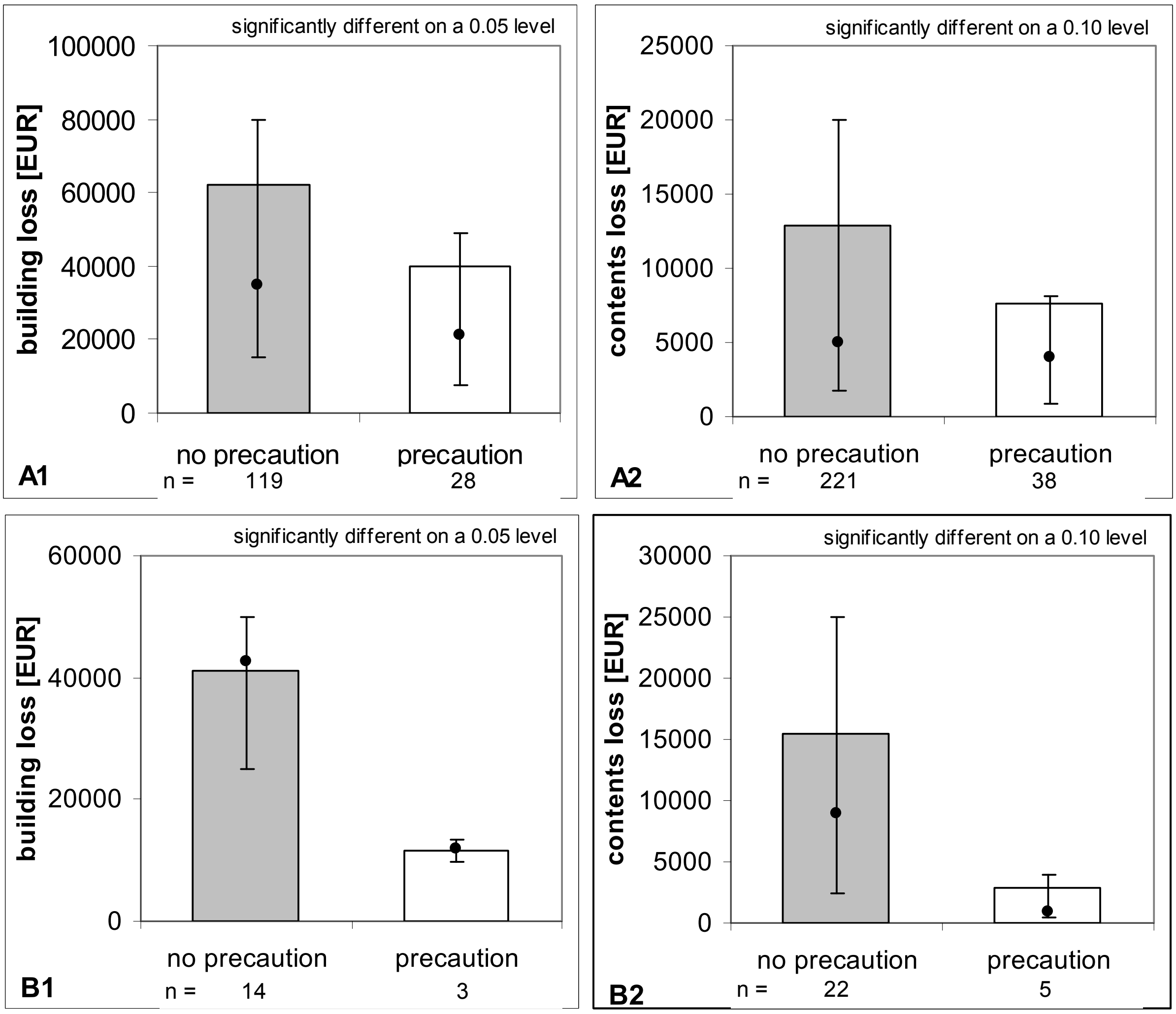

Fig. 6: Absolute building and contents losses of households with and without undertaken precautionary measures in 2002 and 2005/2006 in Dresden. Above, all cases in Dresden are taken into consideration (A1, A2), below only cases with water levels between 60 and 150 cm and no contamination are taken into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

Tab. 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. 2005a).

		without measure undertaken				with measure undertaken			
	mean reduction [%]	n	25%-perc.	median (mean)	75%-perc.	n	25%-perc.	median (mean)	75%-perc.
building loss ratios [%]									
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

Note: * Loss ratios are significantly different on a 0.05 level between the households with and without the undertaken measure.

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. 6B1, 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. 6A1, A2) and is in accordance with an investigation in the whole Elbe catchment (Kreibich et al. 2005a). The investigation of single precautionary measures revealed that flood-adapted use and furnishing were the most effective measures during the extreme flood in August 2002 (Kreibich et al. 2005a). 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).

4 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 a 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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References can be found at the end of the thesis.

Conclusions

In recent years, flooding has caused enormous economic losses in Germany, especially in August 2002. This particular event has initiated a lot of reports, policies as well as research projects aiming at analysing and improving the current flood risk management in Germany (e.g. von Kirchbach et al., 2002; DKKV, 2003; BMU, 2003a, 2003b; www.rimax-hochwasser.de).

To reduce future flood losses in a sustainable manner, flood risk management has to be built upon a sound analysis and assessment of the flood hazard, potential losses and the effectiveness of different mitigation measures. In fact, risk analyses and risk-oriented design, in which the cost-effectiveness of flood defence schemes is evaluated, are gaining more and more attention in water and planning agencies, municipalities as well as (re-)insurances (e.g. USACE, 1996; Olsen et al., 1998; Al-Futaisi and Stedinger, 1999; Kron and Willems, 2002; Ganoulis, 2003; Merz and Thieken, 2004; Merz, 2006). However, some aspects of flood risk analysis and management have not received much attention by now. These include the analysis of the flood hazard at a large scale (i.e. beyond catchment boundaries), the analysis and modelling of flood losses as well as the contribution of precautionary behaviour of residents at risk to the total risk management. The twelve papers of this thesis contribute new results to these topics and thus help to further improve flood risk analysis and management in Germany.

The first section of this thesis dealt with some aspects of analysing and modelling flood hazards in Germany. Despite of difficulties of finding the right number of clusters, the classification of the seasonal occurrence of annual maximum floods throughout Germany resulted in a reasonable spatial pattern of three homogeneous flood regimes. With this map a good overview of the flood hazard in Germany is provided. Further, the flood regimes could be linked to and explained by atmospheric circulation patterns. This was highlighted in detail for the catchment of the river Mulde in the south-east of Germany.

The extent and timing of floods that had caused maximum observed discharges at the gauges under study are consistent with the general flood regimes. These results demonstrate that the analysis of the flood hazard beyond catchment boundaries is crucial for a better understanding of flood patterns and processes. Since the flood regimes seem to change in time, the analysis has to be complemented by further studies that are aimed at identifying and separating long-term fluctuations and trends. A further next step would be the generation of large-scale flood scenarios on the basis of the seasonal flood patterns. For this, a better integration of meteorological knowledge in hydrology is desired.

The flood hazard at a given gauging station is commonly quantified by a flood frequency analysis (FFA). However, FFA is influenced by many uncertainties (see Merz and Thieken, 2005, for a summary). The investigations at the river Rhine demonstrated that discharges connected to a specific flood quantile can alter considerably over time. If questions of how climate change can affect runoff and flood frequencies are addresses, common FFA is reaching its limits since trends in data violate the underlying assumption of FFA. Therefore, the methodology of FFA has to be adapted as already started by Bardossy and Pakosch (2005).

Commonly used FFA also fails to account for retention effects, e.g. due to dike breaches. However, this is an important process in lowland river systems. When regarding extreme events in such river reaches, statistical approaches for flood design have to be complemented by process models that are able to account for dike breaches and retention effects.

The uncertainty range that originates from model applications can, however, be enormous and should hence be quantified and communicated. Particularly, statements about extreme events are fairly uncertain. This is illustrated by the simulations of climate change projections: The uncertainty range increased from mean runoff up to extreme events such as the 100-year flood. Therefore, one challenge for the future is the constant improvement of simulation models. However, since data about extreme events are rare, such models are difficult to evaluate. Thus, the communication of uncertainty to decision-makers and stakeholders will still be an issue, as is the actual decision-making under uncertainty. In addition, efforts of data collection should be increased, particularly after (severe) flood events. For this, procedures and standards for event documentation and data collection have to be developed. This is particularly important in areas that have not received much attention so far, such as flood damage and losses (including damage to flood defence systems such as embankments) and the interaction between different types of flooding (i.e. the spatial-temporal pattern of flash floods, river flooding and consecutive rising groundwater levels).

Besides meteorological, hydrological and hydraulic investigations, risk analyses require an estimation of flood impacts, which is normally restricted to flood losses. Hence, the analysis and modelling of flood losses was focused on in the second section of this thesis.

In the aftermath of the flood in August 2002, 1697 computer-aided telephone interviews were undertaken in flood affected private households. This up-to-date and unique data set enabled us to assess how different variables influence flood losses to buildings and household contents as well as to derive the multi-factorial Flood Loss Estimation MOdel for the private sector - FLEMOps. It was also shown how FLEMOps can be used on the meso-scale if it is combined with census data about the building stock, an asset data base as provided by Kleist et al. (2006) and a dasymetric mapping technique using land cover data.

In contrast to other loss models, FLEMOps+ has also been validated on the micro- as well as on the meso-scale. First evaluations confirmed that the new model was better capable of estimating flood losses than hitherto existing stage-damage-curves. Since it remains unclear whether or in which cases loss models are transferable to other regions or to differing flood situations, more model evaluations are needed.

In general, we still do not know enough about the processes leading to a certain type and amount of flood damage and loss nor about the strengths and weaknesses of damage and loss models. This is alarming in view of the fact that more and more decisions are based on the cost-effectiveness of measures. For this - as well as for other applications such as budgeting of disaster funds - reliable loss models are urgently needed. Since the choice of the loss model influences the final risk estimate to a greater extent than the choice of the hydraulic model as was shown for the case of Eilenburg, model comparisons and loss model validation should be performed more often.

Loss model development, evaluation and updating are limited by a scarcity of damage and loss data. Further, no accepted procedures and methods for damage data collection exist so far. Therefore, standard catalogues of items, which should be recorded (e.g. water level, building type, flood duration), and guidelines for the monetary evaluation of losses are to be developed. A first suggestion for the documentation of mountain disasters was already made by Hübl et al. (2002). For flood disasters, a guideline is currently in preparation in the framework of the project Methods for the Evaluation of Direct and Indirect flood losseS (MEDIS). Moreover, data collection after disastrous events has to be seen as a fixed element of the whole risk management process. Thus, this task should be scheduled in work plans of disaster management organisations, and training of loss evaluators should take place.

To reduce future flood losses, risk analyses have to be followed by flood risk reduction programs. Different measures in Germany were analysed after the August 2002 flood within a "Lessons Learned"-study, which is part of the third section of this thesis. Among others, the study revealed a huge lack of standardisation in flood hazard mapping, of considering extreme events and of linking hazard zones to land use planning. After the flood in 2002, there have been first attempts to close this gap. These efforts are currently supported by the new European flood directive (EU, 2007). However, heterogeneity of hazard maps in Germany with regard to the map content, scale and accessibility will remain.

The survey data used for the development of FLEMOps were also valuable for a broader analysis of vulnerability and coping capacities of affected private households. Regional differences in preparedness, response, financial losses and recovery could be explained by differences in flood experience and flood impact. Knowledge about self-protection, residents' homeownership and household size influenced the extent and type of private precaution as well as the residents' ability to perform mitigation measures. To enhance coping capacities of exposed residents, they have to be better informed about potential hazards (i.e. about potential flood scenarios). To strengthen risk awareness, hazard maps have to be accessible for the public and should be accompanied by information about appropriate behaviour during an event and effective self-protection measures.

In 2002, flood warning was insufficient. By now, many efforts to improve warning systems, simulation models and dissemination channels for better and reliable flood warnings have been undertaken. However, in many cases the improvement of warning systems is guided by technological aspects. To achieve loss reduction, the communication of warnings to the exposed public is, however, an important element that is often neglected. Released flood warnings should at least include more information about what to do in the case of a flood.

The analysis also leads to the conclusion that not all residents have the same abilities for self-protection. Homeowners have more options for retrofitting and flood-adapted construction than tenants. Elderly people and singles probably have lesser capabilities to perform emergency measures than big families. Therefore, information leaflets for specific groups of people, e.g. tenants, homeowners, elderly people or young families, have to be developed in order to convince them that they can contribute to loss mitigation. Moreover, improved response capacities, such as neighbourhood networks, should be activated. To improve private loss mitigation even more, flood insurance contracts should include appropriate incentives for self-protective actions. However, there is some evidence that insurance companies do little to encourage precautionary behaviour of the insured. Thus, flood hazards and mitigation options are to be better communicated to insurers, as well.

In March 2005 and in April 2006, the Elbe was hit by floods again. Although these events were less severe than in 2002, they proofed considerable improvements in risk management and preparedness in the city of Dresden. For a sustainable risk reduction, it is important that we succeed in constantly maintaining loss mitigation measures and in keeping public and private preparedness at a high level - also without recurrent flooding. Therefore, risk communication has to frequently recall past flood experiences, e.g. by flood marks, commemoration days etc. Finally, methods for risk monitoring have to be developed so that we are alerted if risk awareness and coping capacities are starting to fade. For these challenges, interdisciplinary research and the involvement of stakeholders in transdisciplinary research projects is needed.

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