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Estimation uncertainty of direct monetary flood damage to buildings

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Abstract. Traditional flood design methods are increasingly supplemented or replaced by risk-oriented methods which are based on comprehensive risk analyses. Besides meteorological, hydrological and hydraulic investigations such analyses require the estimation of flood impacts. Flood impact assessments mainly focus on direct economic losses using damage functions which relate property damage to damage-causing factors. Although the flood damage of a building is influenced by many factors, usually only inundation depth and building use are considered as damage-causing factors. In this paper a data set of approximately 4000 damage records is analysed. Each record represents the direct monetary damage to an inundated building. The data set covers nine flood events in Germany from 1978 to 1994. It is shown that the damage data follow a Lognormal distribution with a large variability, even when stratified according to the building use and to water depth categories. Absolute depth-damage functions which relate the total damage to the water depth are not very helpful in explaining the variability of the damage data, because damage is determined by various parameters besides the water depth. Because of this limitation it has to be expected that flood damage assessments are associated with large uncertainties. It is shown that the uncertainty of damage estimates depends on the number of flooded buildings and on the distribution of building use within the flooded area. The results are exemplified by a damage assessment for a rural area in southwest Germany, for which damage estimates and uncertainty bounds are quantified for a 100-year flood event. The estimates are compared to reported flood damages of a severe flood in 1993. Given the enormous uncertainty of flood damage estimates the refinement of flood damage data collection and modelling are major issues for further empirical and methodological improvements.

1 Introduction

Traditional flood design methods are increasingly supplemented or replaced by risk-oriented methods which are based on comprehensive risk analyses. In the context of risk-oriented design, flood risk encompasses the flood hazard (i.e. extreme events and associated probability) and the consequences of flooding. Flood risk analysis has to take into account all relevant flooding scenarios, their associated probabilities, their physical effects and should yield the full distribution function of the flood consequences. Besides meteorological, hydrological and hydraulic investigations such analyses require the estimation of flood impacts.

Usually, flood impact assessments are limited to detrimental impacts even though there may be positive consequences, e.g. the replenishment of groundwater or the maintenance of high biological diversity in floodplains due to inundations. Flood damages can be classified into direct and indirect damage. Direct damages are those which occur due to the physical contact of the flood water with humans, property or any other objects. Indirect damages are damages which are induced by the direct impacts and may occur – in space or time – outside the flood event. Examples are disruption of traffic, trade and public services. Usually, both types of damages are further classified into tangible and intangible damage, depending on whether or not these losses can be assessed in monetary values (Smith and Ward, 1998).

The largest part of the literature on flood damages concerns direct tangible damage. Other damage types have received much less attention. Some exceptions are the estimation of loss of life (Brown and Graham, 1988; DeKay and McClelland, 1993; Funnemark et al., 1998; BUWAL, 1999), psychological damage and stress (Bennet, 1970; Green et al., 1987; Green and Penning-Rowsell, 1989; Penning-Rowsell and Fordham, 1994; Penning-Rowsell et al., 1994; Krug et al., 1998), or indirect monetary damage (Parker et al., 1987; Montz, 1992; FEMA, 1998; Olsen et al., 1998). 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

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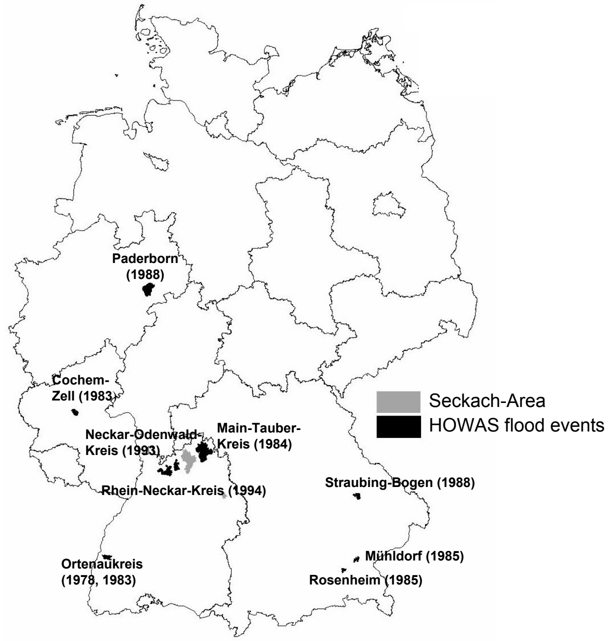

Fig. 1. Flood events of the German flood damage data base HOWAS and the test area Seckach

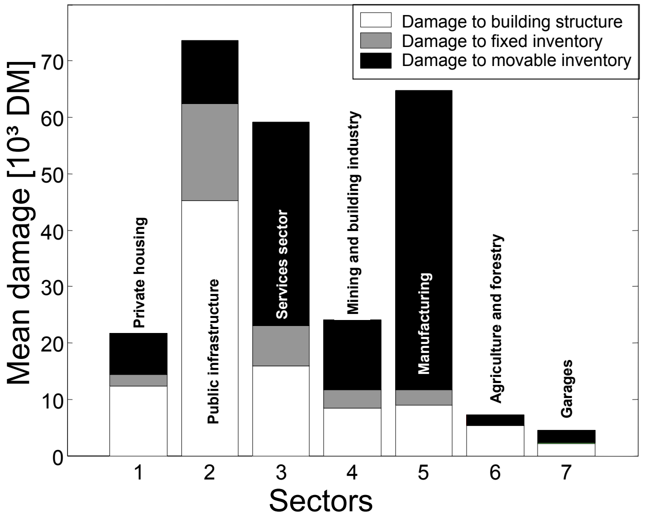

Fig. 2. Mean damage (total damage, damage to building structure, damage to fixed inventory, damage to movable inventory) per economic sector

Green, 2000) these damage categories are not treated here. The present study is limited to direct monetary flood damage to buildings, the only damage type for which a large data base exists in Germany.

A central idea in flood damage estimation is the concept of damage functions or loss functions. Such functions give the building damage due to inundation. Most damage models have in common that the direct monetary damage is obtained from the type or use of the building and the inundation depth (Wind et al., 1999; NRC, 2000). 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 2 m above the building floor?". On the base of such actual and synthetic data generalized relationships between damage and flood characteristics have been derived for different regions. Probably the most comprehensive approach has been the Blue Manual of Penning-Rowsell and Chatterton (1977) which contains stage-damage curves for both residential and commercial property in the UK.

It is obvious that flood damage depends, in addition to building type and water depth, on many factors. Some of these factors are flow velocity, duration of inundation, sediment concentration, availability 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). Although a few studies give some quantitative hints about the influence of other factors (Smith, 1994; Wind et al., 1999; Penning-Rowsell and Green, 2000; IKSR, 2002) there is no comprehensive approach for including such factors. 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". Given this situation the uncertainty of flood damage estimations is expected to be high.

Since it has been shown that ignoring uncertainty can lead to decisions different from more informed decisions using uncertainty estimates (USACE, 1992; Peterman and Anderson, 1999) the uncertainty of flood damage estimates should be quantified. Therefore the present paper quantifies the uncertainty which is associated with flood damage estimates. This uncertainty analysis is built upon the most comprehensive flood damage data set which is available in Germany.

2 Data set

The present study analyses data of the HOWAS data base held at the Bavarian Water Management Agency, Munich. HOWAS contains information about the flood damage of approximately 4000 buildings and is the most comprehensive flood damage data base in Germany. The damages were caused by nine floods between 1978 and 1994 in Germany (Fig. 1). Damage values of HOWAS were estimated by damage surveyors of the insurance companies which were responsible for the insurance compensation. The damage estimates are considered to be very reliable because they were the basis of the financial compensation.

Table 1. Information used from the flood damage data base HOWAS.

Event & Location	Information about the flood event and the location of the building (year of the flood event, community etc.)
Building use	Buildings are classified into 6 economic sectors: 1. private households 2. public infrastructure (e.g. transformer station, schoolhouse, fire station) 3. services sector (e.g. supermarket, restaurant) 4. mining and building industry (e.g. civil engineering, carpentry, installers workshop) 5. manufacturing (e.g. beverage industry, metal processing, wood processing) 6. buildings for agriculture, forestry and horticulture Building use is specified by a 4-digit number, e.g.: 1000: private households 1100: single building, bungalow 1110: solid structure, built before 1924 1111: no cellar, no garage 2000: public infrastructure 2181 : post office 2628: architectural/cultural monuments
Water stage	Height above the ground floor or height above the cellar floor (if the water flooded only the cellar)
Damage	Damage is split in: → Cellar: damage to building fabric, fixed inventory and movable inventory → Storeys: damage to building fabric, fixed inventory and movable inventory → Damage to grounds

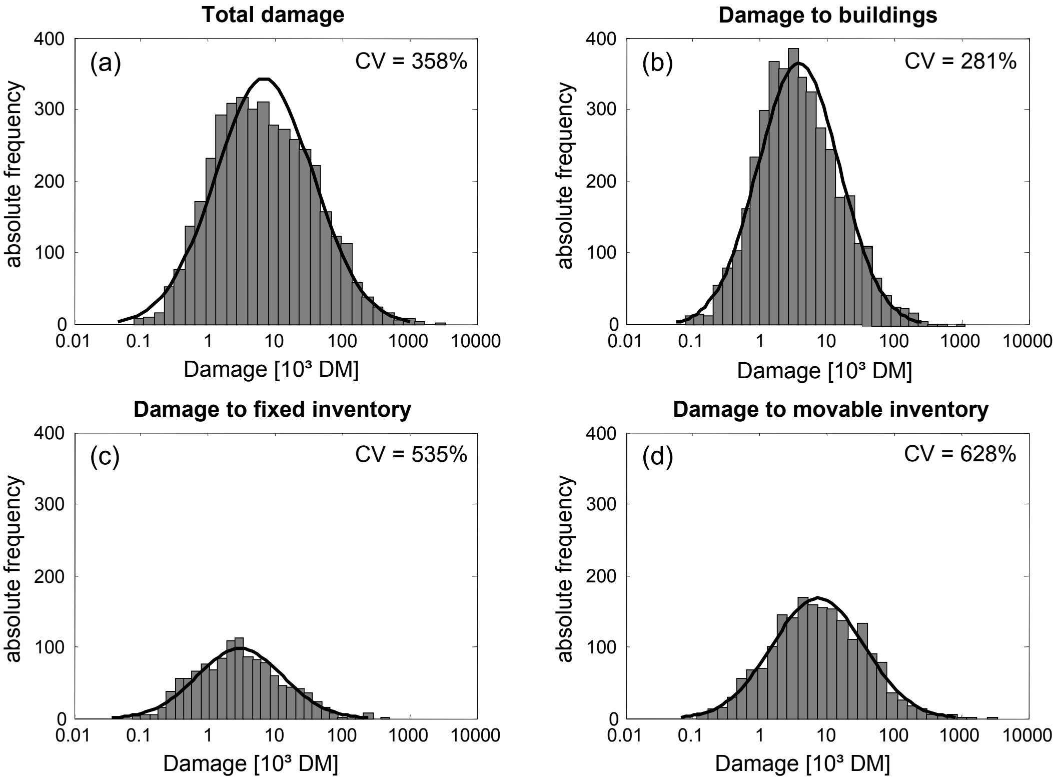

Fig. 3. Histograms of damage values for total damage **(a)**, damage to building structure **(b)**, fixed inventory **(c)** and movable inventory **(d)** for all records of the HOWAS data base.

Table 2. Number of damage records in HOWAS per economic sector.

Economic sector	Number	Fraction (%)
Private households	1735	43.0
Public infrastructure	155	3.8
Services sector	623	15.4
Mining and building industry	68	1.7
Manufacturing	291	7.2
Agriculture and forestry	518	12.8
Garages	648	16.1
Sum	4038	100

Each data set of HOWAS contains information about one flood-affected building. Table 1 lists the information given for each building and flood event. Some other interesting parameters (reinstatement value, floor space etc.) are not available for all records. Therefore, the study is limited to the items given in Table 1. Damages to buildings have to be interpreted as restoration costs, those concerning inventory as replacement costs. All costs are given in German Mark and have been converted to the year 1991. Conversion factors are the price indexes for construction works on residential buildings published by the Federal Statistical Office Germany. It has to be stressed that the HOWAS data base contains absolute damage values. Since there is no access to the information about the value of the buildings it is not possible to derive relative damage statements, expressing the expected damage as fraction of the value of the building fabric and the inventory.

Table 2 shows the number of data sets per economic sector. More than 40% of all records belong to the sector private housing. Due to their large number garages have been analysed separately.

3 Variability of flood damages

3.1 Descriptive statistics of flood damage records

HOWAS differentiates between damage to building structure, damage to fixed inventory and damage to movable inventory. Figure 2 shows the mean value of those damage fractions for the economic sectors. The total damage and the damage fractions vary significantly from sector to sector. The largest damage occurs in the sector “public infrastructure”, followed by the sector “manufacturing”. Although the total damage is similar for both sectors, the damage fractions are very different. The damage of the sector “public infrastructure” is dominated by the damage to the building structure, whereas the main share of the damage of the sector “manufacturing” results from the damage to the movable inventory. This is probably due to complex, large buildings and constructions in the sector “public infrastructure” and to sophisticated, special machinery and equipment in the sector “manufacturing”. In contrast are the generally relatively simple buildings for “agriculture and forestry” or even “garages” with basic or no inventory. Thus “garages” and “agriculture and forestry” show the smallest mean damage values and in both sectors nearly no damage to fixed inventory occurs. In summary, the mean values (for the total damage and the damage fractions) are comprehensible.

Figure 3 shows the histograms of the damage values for (a) total damage of a flood-affected building, and split into the fractions (b) damage to building structure, (c) damage to fixed inventory and (d) damage to movable inventory. Since the samples are positively skewed their logarithms were plotted. The samples follow more or less a Lognormal distribution. This observation is not only valid for the complete data set but also for the samples of the different economic sectors.

Figure 3 also illustrates the large variability in the data set. The coefficient of variation (CV) varies between 281% for the damage to building structure and 628% for the damage to movable inventory. This large variability is not surprising due to the fact that the data base contains very different objects which were damaged under various conditions. To reduce this large variability the complete data set was divided into different subsets. Due to space restrictions only the analysis of the total damage values is presented. The results for the damage fractions are not shown here.

Figure 4 illustrates the variability of the total damage when the data set is divided according to (a) the building use, (b) the water depth category and (c) both, the building use and the water depth category. The variability of the complete data set (CV=358%) is clearly reduced by considering the building use. For six sectors the CV varies between 154 and 230%. The only exception is the sector “manufacturing” with a CV of 434%. A reduction of the variability is also obtained when the data set is divided according to the water depth category, i.e. when the flood water affected only the cellar (“flooded cellar only”) or when the inundation also affected the storeys (“flooded storeys”). The combination of both criteria divides the complete data set in 14 subsets (7 building uses and 2 water depth categories) which are given in Table 3. With the exception of the subset “manufacturing; flooded storeys” the variability of all subsets is significantly reduced. Further divisions, i.e. consideration of more detailed building use or finer water depth categories, did not reduce the variability (data not shown).

3.2 Depth-damage functions

It has been shown in the previous section that the consideration of the economic sectors and of the water depth explains some of the variability in the HOWAS data set. To test the usefulness of depth-damage functions a nonparametric regression between the total damage and the water depth was performed for the different sectors. This regression uses the Epanechnikov kernel with a width of 0.6 m (Härdle, 1990). Figure 5 shows the scatter plot and the nonparametric depth-damage function of the sectors “private housing” and

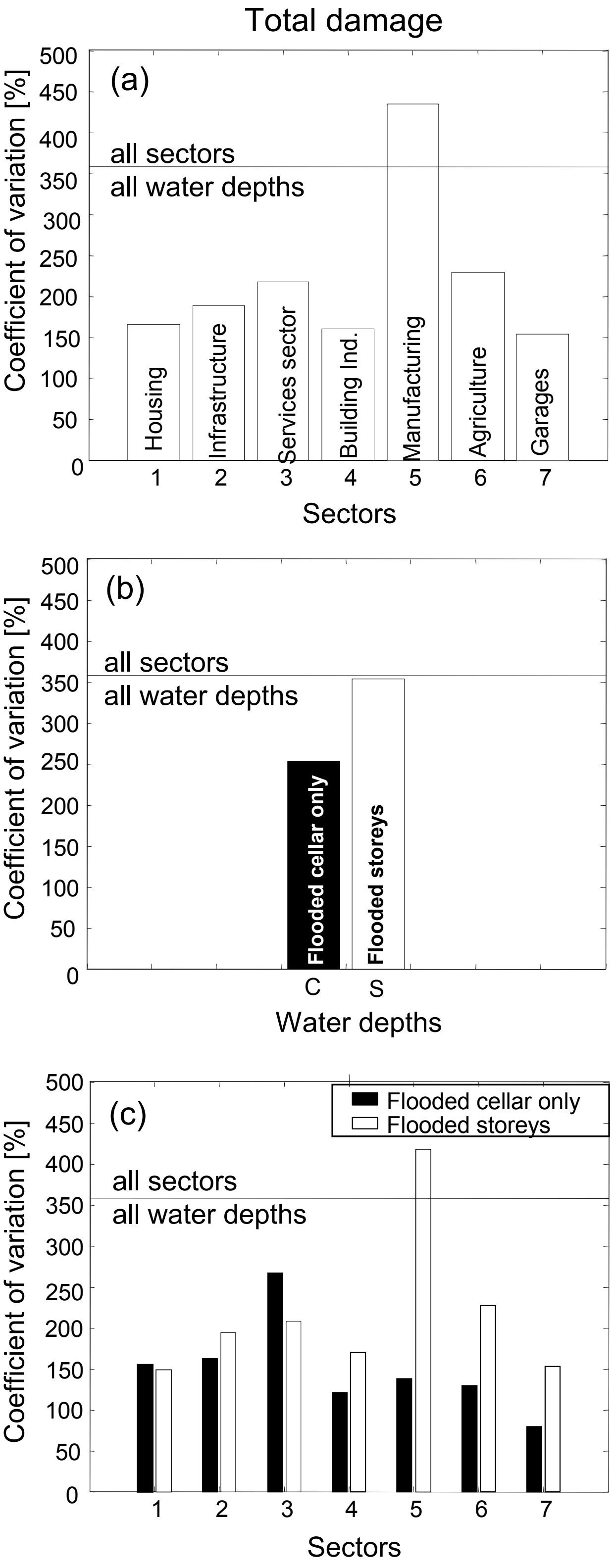

Fig. 4. Decrease of variability by dividing the damage data according to building use **(a)**, water depth category **(b)** or both **(c)**.

Table 3. Subsets of the HOWAS data base.

Subset	Number	Mean damage (10^3 DM)	CV (%)
Private households; flooded cellar only	831	13	155
Private households; flooded storey	904	30	149
Public infrastructure; flooded cellar only	34	65	162
Public infrastructure; flooded storey	121	79	194
Services sector; flooded cellar only	123	37	266
Services sector; flooded storey	500	73	208
Mining and building industry; flooded cellar only	9	41	120
Mining and building industry; flooded storey	59	25	169
Manufacturing; flooded cellar only	39	17	137
Manufacturing; flooded storey	252	74	418
Agriculture and forestry; flooded cellar only	34	3	129
Agriculture and forestry; flooded storey	484	8	227
Garages; flooded cellar only	23	2	79
Garages; flooded storey	625	5	153
All damage records	4038	29	358

“services sector”. The scatter plot shows an enormous variability, e.g. for a water depth of 1 m the total damage of the sector “private housing” varies from 375 DM to 63 527 DM. Further, the regression illustrates that the water depth explains only a small part of the total variability. This result is in line with other studies which stress the importance of additional damage-influencing factors, besides water depth and building use (Smith, 1994; Penning-Rowsell et al., 1994; USACE, 1996).

Therefore, absolute depth-damage functions are not very useful in explaining the variability of the damage data. Of course, by using their expert knowledge flood damage experts may extract useful depth-damage curves by means of the HOWAS data base. However such an approach complicates a formal quantification of uncertainty and is not further elaborated here.

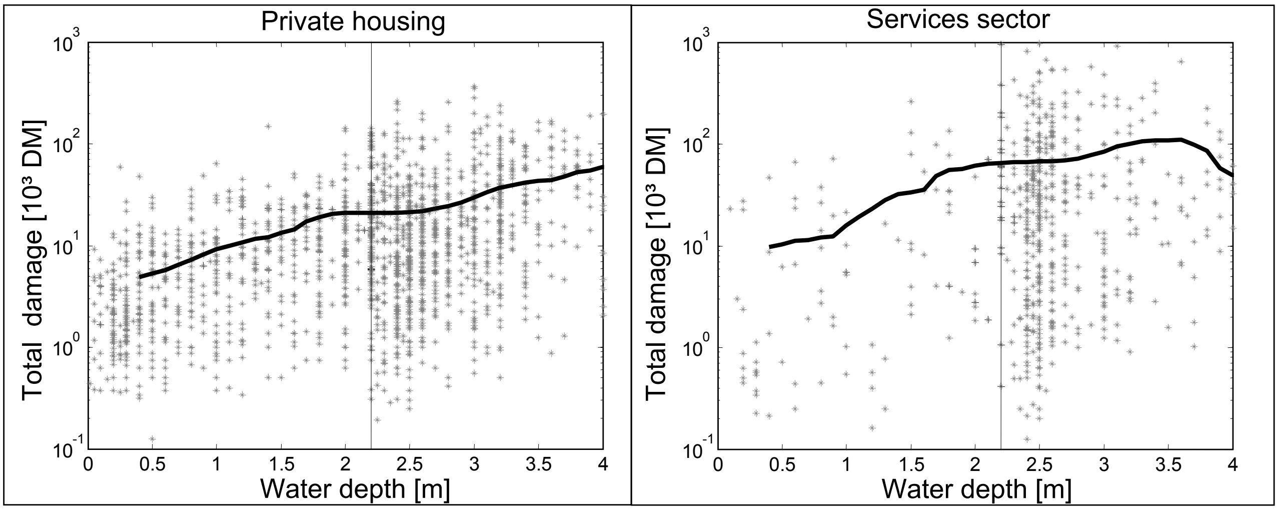

Fig. 5. Scatter plot for the economic sectors "private housing" and "services sector" and nonparametric depth-damage functions (Epanechnikov-kernel, bandwidth = 0.6 m). The line at water depth $h = 2.2$ m divides the cases where the flood water affected only the cellar ("flooded cellar only"; $h < 2.2$ m) and the cases where the inundation also affected the storeys ("flooded storeys"; $h > 2.2$ m).

4 Quantification of uncertainty of damage estimates

To estimate flood damage we assume that the HOWAS data base is representative for flood damages in Germany and that we may transfer the HOWAS data within Germany. Because the depth-damage functions derived in Sect. 3.2 explain only a small part of the variability the mean values of the 14 subsets (Table 3) were further used for this purpose. For a given flood scenario all inundated buildings within the flooded area, their building use and their water depth are determined. Then the total flood damage d is estimated as:

$$d = \sum_{j=1}^{14} n_j \overline{d}_j \qquad (1)$$

where n_j is the number of buildings of the subset j in the flooded area, and $\overline{d}_j$ is the mean damage of the subset j.

Given the large variability of the damage data the uncertainty of building-specific damage estimates may be very large. Fortunately, in most cases it is not necessary to estimate the damage for single buildings, but estimates are needed for larger areas, e.g. river reaches or towns, containing many buildings. Figure 6 shows the 2.5 and 97.5% percentiles for the total damage depending on the number of flooded buildings. Exemplarily the sectors "private housing" (a) and "manufacturing" (b) both divided into the water depth categories: "flooded cellar only" and "flooded storeys" are presented. The percentiles were calculated by a Monte Carlo simulation. For a given number m of affected buildings 10^5 values were randomly generated from the statistical properties of the subset. This sample was divided in k subsamples of size m ($k \times m = 10^5$). Then mean values for each subsample were calculated. From the resulting sample of size k the 2.5 and 97.5% percentiles were extracted. This numerical approach was chosen due to the more realistic results of only positive damage values in contrast to confidence intervals assuming a normal distribution. The percentile-curves are skewed since all values are ≥ 0.

For example, Fig. 6 shows that we have a large uncertainty if we want to estimate the flood damage of a single building of the use "private housing" with water in the storey. With a probability of 95% the true but unknown damage is between 700 and 212 000 DM. The uncertainty of damage estimates decreases with increasing number of flooded buildings as shown in Fig. 6. Due to the different variances of the subsets, the magnitude of the uncertainty reduction differs between the sectors. For instance, the uncertainty of a flood estimate for an industrial area is much larger than for a residential area when the same number of buildings is affected. With these confidence intervals, the minimal number of flooded buildings for reliable damage estimation in an area of interest can be given. For example, if we want to have a 95% confidence interval with a deviation of at most ±10% from the total estimated damage in a residential area, the area has to cover a minimum number of 852 buildings with the storeys flooded. On the other hand, the uncertainty of a damage estimation in a specific area with a certain amount of affected buildings can be determined. For example, if in the study area 2000 residential houses are flooded up to the storeys, with a probability of 95% the true but unknown total damage lies between the estimated value ±6.5%.

5 Example applications

5.1 Example Seckach area

Flood damage and its uncertainty was estimated in the rural Seckach area (Fig. 1) which was severely damaged by a flood in 1993 that was classified as a 100–year flood. Reported

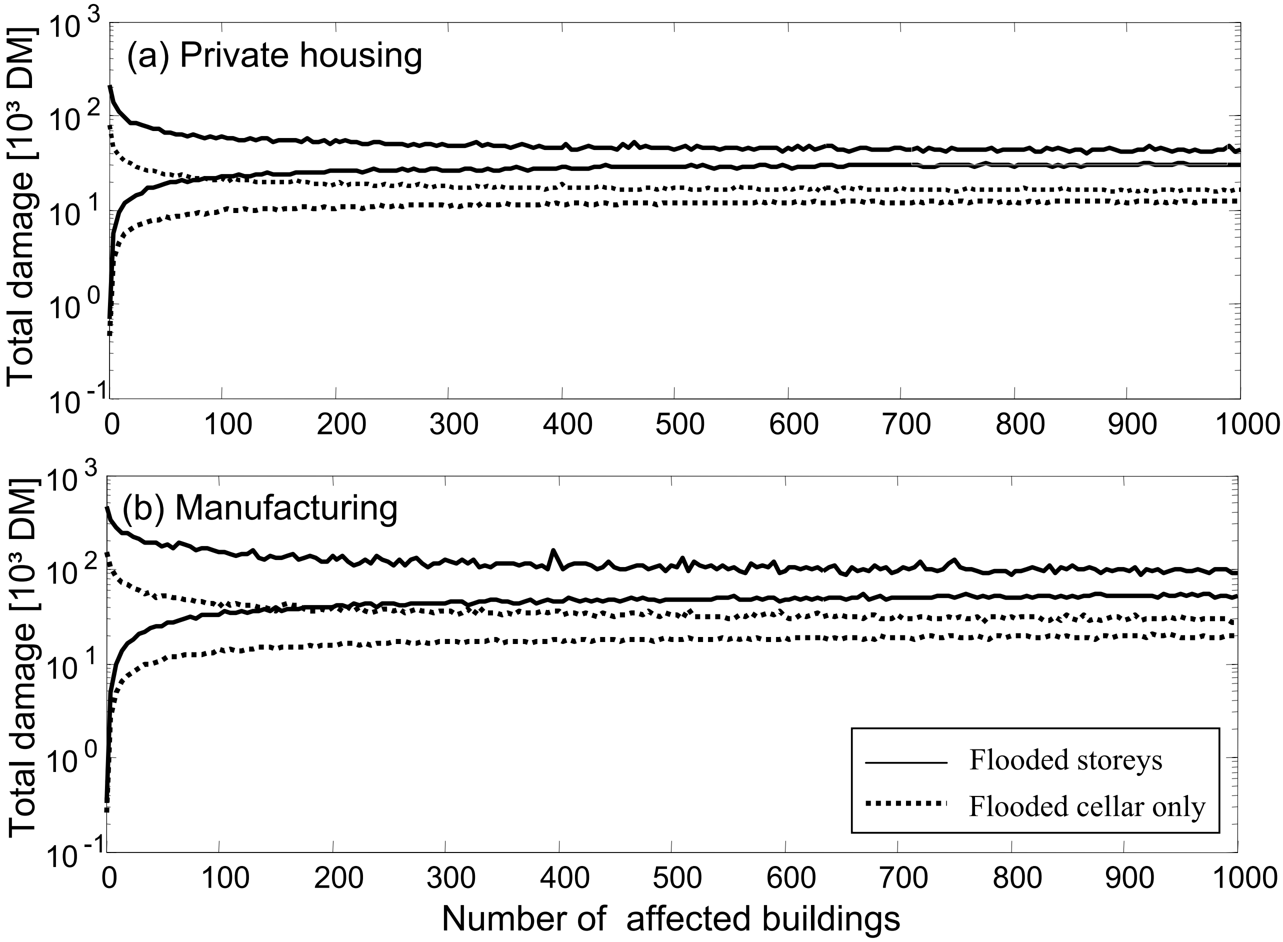

Fig. 6. 2.5 and 97.5% percentiles for the total damage of four subsets depending on the number of flooded buildings obtained by Monte-Carlo simulation. The sectors "private housing" **(a)** and "manufacturing" **(b)** both divided into the water depth categories "flooded cellar only" and "flooded storeys" are shown.

Table 4. Number and share of residential, commercial and industrial buildings with an inundated area of more than 15 m^2 for the 100–year flood scenario.

Economic Sector	Residential buildings		Services/Commerce		Manufacturing/Industry		Total
Site	Buildings	Share	Buildings	Share	Buildings	Share	Buildings
Adelsheim	149	69%	18	8%	50	23%	217
Buchen	32	78%	2	5%	7	17%	41
Möckmühl	59	63%	29	31%	6	6%	94
Osterburken	46	53%	18	21%	23	26%	87
Roigheim	3	14%	2	9%	17	77%	22
Rosenberg	37	76%	3	6%	9	18%	49
Seckach	64	60%	29	27%	13	12%	106

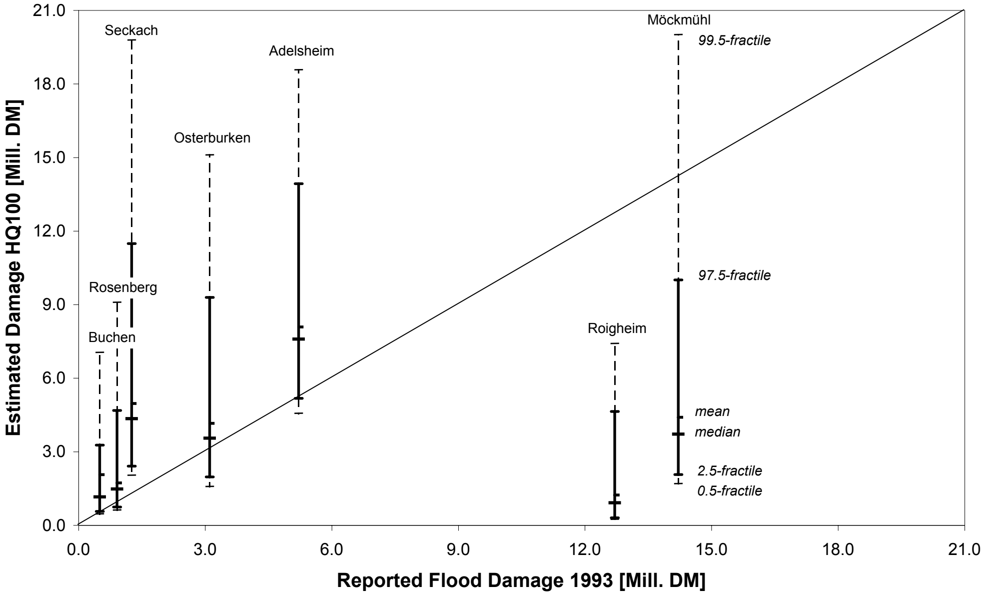

Fig. 7. Estimated flood damages versus reported flood damages for a 100–year flood in seven rural communities.

Table 5. Mean damages in the HOWAS data base and during the 1993 flood.

	HOWAS data base	Insured losses in Seckach/Kirnau 1993	Not insured losses Seckach/Kirnau 1993	Insured flood losses in Baden-Würrtemberg 1993 (Bayerische Rück, 1994)	Flood losses in Rheinland-Pfalz 1993 (Bayerische Rück, 1994)
Residential buildings	22 050 DM	14 050 DM			8 650 DM
Commerce	65 600 DM	51 170 DM			46 440 DM
Industry	66 200 DM	25 590 DM			
No differentiation of building use	29 440 DM	16 470 DM	69 090 DM	16 000 DM Variation per region: 3 000–27 000 DM	15 000 DM Variation per region: 6 930–50 410 DM

flood damages and notifications of claims were provided by the municipalities and a regional building insurance company, respectively. From the municipalities flood damages were especially collected in the industrial and commercial sector, whereas the insurance data mainly contains damages to residential buildings.

To optimise the flood defence system, flood scenarios for return periods of 10, 20, 50, 100, 200, 500 and 1000 years were calculated for the urban areas in the Seckach area for the current flood defence as well as for improved flood protection. The sites belong to seven municipalities (Adelsheim, Buchen, Möckmühl, Osterburken, Roigheim, Rosenberg and Seckach).

The estimation of the total flood damage per municipality and its associated uncertainty was carried out for the inundation scenario of the 100–year flood. Flood damage and its uncertainty was estimated per economic sector based on the HOWAS data analysis without consideration of inundation depth, i.e. only taking into account the building use. For each economic sector the number of flooded buildings with an inundated area of more than 15 m^2 was determined (Table 4). The number of buildings with a mixed use were assigned one half each to the sectors residential buildings and services sector. Given the number of inundated building per sector as well as the mean and standard deviation of flood damages in that sector based on the HOWAS data base, one realisation of the damage was computed by means of a Lognormal random number generator. This estimation was repeated for each sector. The estimates per sector were added up and resulted in one estimate for the total damage per municipality. This procedure was repeated 1000 times so that 1000 possible estimates for the total flood damage in one municipality were available that reflect the variability of flood damages according to HOWAS. Then percentiles, mean and standard deviation of the generated total sums per municipality were determined and compared to the damages reported in 1993.

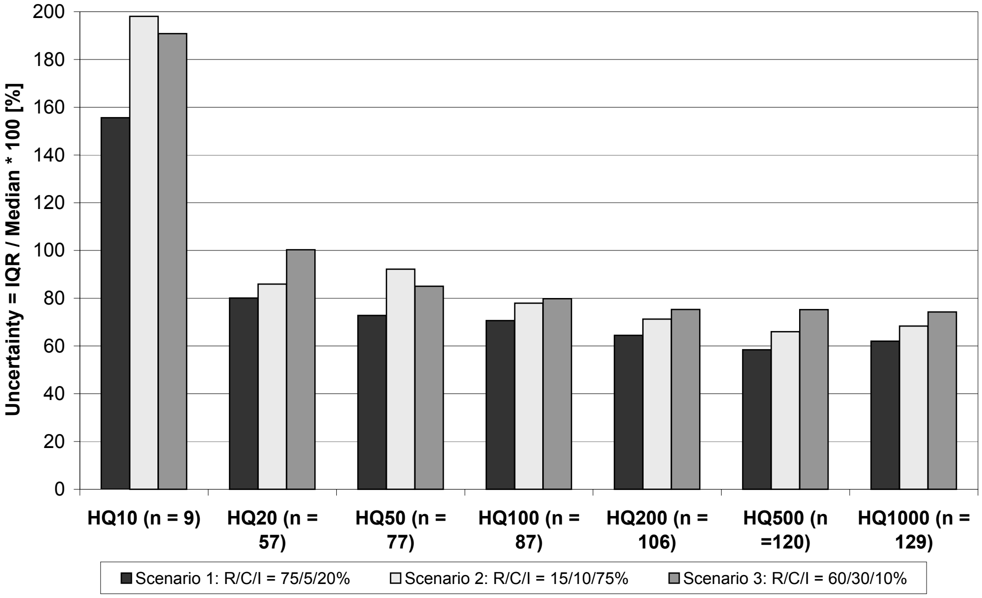

Fig. 8. Influence of building use composition on the uncertainty of flood damage estimates for different return periods. Considered economic sectors: private housing, services sector and manufacturing.

Such a comparison was only possible for residential buildings, the services sector and manufacturing.

The mean and median estimates for the total damage per municipality as well as their 95%- and 99%-confidence intervals are shown in Fig. 7. This example illustrates the large uncertainty in flood damage estimation. The reported flood damages of four municipalities are situated within the limits of the 95% confidence interval, five reported flood damages lie within the range of the 99% confidence interval, whereas in two municipalities the reported flood damages lie even outside the 99% confidence interval.

While our estimates for Roigheim and Möckmühl tend to be too low due to a high percentage of industrial and commercial buildings (see below), our calculations tend to overestimate the damages in the remaining municipalities. One reason for this might be that the mean damages per sector based on the HOWAS data base are higher than the mean insured losses in our investigation area (Table 5). The mean losses in the Seckach area are in the same order of magnitude as the average loss due to the 1993 flood in whole Federal State of Baden-Württemberg and Rhineland-Palatinate (Table 5).

Especially in the sector manufacturing the variability is most likely higher than the range covered in HOWAS. Whereas in HOWAS the highest damage in the industrial sector is 3.43 Mill. DM, the highest insured flood loss of the 1993 flood was twice as much in Baden-Württemberg (7 Mill. DM, Bayerische Rück, 1994) and the highest reported industrial damage was nearly fourfold (12.2 Mill. DM) in the Seckach area (at site Roigheim). Therefore it has to be concluded that the HOWAS data base is not totally representative for flood damages in Germany and should be enlarged.

An additional source of uncertainty results from the assumption that the damages of the 1993–flood can be compared to the damages of the 100–year flood scenario. Flood frequency analysis based on data from one discharge gauge in the Seckach area found that the 1993–flood had a return period of approximately 100 years. The 100–year scenario is a synthetic scenario based on the design rainfall method. Therefore the inundation area of the 100–year flood scenario might not be equivalent to the inundation area of 1993–flood. There also exists an unknown but probably large uncertainty about the reported flood damage data: one notification of claim might contain several buildings, especially if industrial sites were affected, but we do not have information about the number of buildings per claim. Further, more than one notification of claim could be made in the same building if buildings with a mixed use (e.g. housing and commerce) were involved. Moreover, it is unclear whether or not all damages (i.e. damages to buildings as well as to inventory) were included in the insurance data and whether or not deductibles must be added. Wind et al. (1999) estimate that the uncertainty concerning the number of reported flood damages amounts to 20% while the uncertainty of object-specific flood damage estimation amounts to 20–40%. For a better comparability of actual and estimated flood losses, it is of particular importance that flood damage data are collected whenever possible and that the procedure of data collection is transparent and follows an accepted standard.

5.2 Influence of building use on the uncertainty of damage estimation

The influence of the distribution of the building use within a flooded area on the uncertainty of the damage estimate is demonstrated using inundation scenarios for different return periods and three synthetic building composition scenarios. The building composition scenarios are based on Table 4. The first scenario reflects the situation in Adelsheim, Buchen and Rosenberg, i.e. residential, commercial and industrial buildings are assumed to cover 75%, 5% and 20% of the affected buildings, respectively. The second scenario illustrates the situation in Roigheim with 15% residential, 10% commercial and 75% industrial buildings. In the third scenario buildings are composed according to Möckmühl and Seckach with 60% residential, 30% commercial and 10% industrial buildings.

Figure 8 shows the influence of the building composition on the uncertainty of the damage estimation (measured as the interquartile range / median * 100; IQR/M) for scenarios of different return periods. The more severe the inundation scenario, the higher is the number of affected buildings and thus the lower is the uncertainty of the damage estimation. A high percentage of residential buildings (scenario 1) yields the smallest uncertainty, whereas a high percentage of industrial buildings (scenario 2) or a moderate percentage of commercial buildings (scenario 3) cause an increase in uncertainty. That means that flood damages can be estimated most reliable in residential areas. To reach a comparable reliability of estimation in an area dominated by industry or commerce the number of affected buildings must be higher. For example, IQR/M of 80% is reached with 57 buildings for the building composition dominated by residential buildings (scenario 1), whereas the scenario with 30% commercial buildings (scenario 3) needs 87 buildings to reach the same reliability. In general, the quality of the damage estimate depends on how well the used data base represents the actual building mix in the study area. That means, the smaller the flood-prone river corridor, the more accurate has to be the damage data selection used for generating site specific statistical information.

6 Conclusions

This paper analyses a data set of approximately 4000 flood damage records. Each record represents the direct tangible damage to an inundated building. The analysis shows that the damage data follow a Lognormal distribution with large variability. The consideration of building use and water depth, by dividing the data set into subsets, partly reduces the variability of the data. Since the remaining variability is still considerable it is concluded that more damage-influencing factors have to be taken into account to accurately estimate flood damages. The classification according to economic sectors may be a good approach for damage to inventory. For damage to building structure a division of the damage data according to building types (timber structure, masonry, concrete buildings etc.) may lead to better results. Further, it is shown that absolute depth-damage functions which relate the total damage to the water depth are not very helpful in explaining the variability of the damage data, because damage is determined by various parameters besides the water depth. It is expected that relative depth-damage functions which give the degree of damage as a function of water depth are more appropriate, since they are at least independent from the absolute values of buildings and inventory.

The paper quantifies the uncertainty which is associated with damage estimates using statistical information. It is shown that the uncertainty depends on the number of flooded buildings and on the distribution of building use within the flooded area. Statistically derived damage estimates for single buildings are extremely problematic due to the high uncertainty. For economic sectors with high variability, e.g. manufacturing, specific local information may be essential. For larger or very special objects it is necessary to derive damage estimates through personal interviews with plant managers, property owners etc. (Smith, 1994; USACE, 1996; Booysen et al., 1999). Given the enormous uncertainty of flood damage estimates, cost-benefit analyses for flood defence schemes may be highly uncertain. In view of these results the refinement, standardisation and validation of flood damage data collection and modelling are major issues for further improvements.

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References

Bayerische Rück: Das Weihnachtshochwasser 1993/94 in Deutschland, Sonderdruck 16, München, 1994.

Bennet, G.: Bristol floods 1968: controlled survey of effects on health of local community disaster, Br. Med. J., 3, 454–458, 1970.

Booysen, H. J., Viljoen, M. F., and de Villiers, G.: Methodology for the calculation of industrial flood damage and its application to an industry in Vereeniging, Water SA, 25(1), 41–46, 1999.

Brown, C. A. and Graham, W. J.: Assessing the threat to life from dam failure, Water Resour. Bull., 24, 1303–1309, 1988.

BUWAL (Bundesamt für Umwelt, Wald und Landschaft): Risikoanalyse bei gravitativen Naturgefahren, Umwelt-Materialien 107/l, Bern, 1999.

DeKay, M. L. and McClelland, G. H.: Predicting loss of life in case of dams failure and flash flood, Risk Anal., 13(2), 193–205, 1993.

FEMA (Federal Emergency Management Agency): Costs and benefits of natural hazard mitigation, Federal Emergency Management Agency, Washington D. C., 1998.

Funnemark, E., Odgaard, E., Svendsen. V. N., and Amdal, T.: Consequence analysis of dam breaks, in: Dam safety, Balkema, edited by Berga, L., Rotterdam, 329–336, 1998.

Green, C. H. and Penning-Rowsell, E. C.: Flooding and the quantification of “intangibles”, J. Instn. Wat. & Envir. Mangt., 3(1), 28, 1989.

Green, C. H., Penning-Rowsell, E. C., and Parker, D. J.: Estimating the risk from flooding and evaluating worry, in: Uncertainty in risk assessment, management, and decision making, edited by Covello, V. T., Lave, L. B., Moghissi, A. and Uppuluri, V. R. R., Plenum Press, New York, London, 159–175, 1987.

Grigg, N. S. and Helweg, O. J.: State-of-the-art of estimating flood damage in urban areas, Water Resour. Bull., 11(2), 379–390, 1975.

Härdle, W.: Applied nonparametric regression, Cambridge University Press, Cambridge, 1990.

IKSR (International Commission for the Protection of the Rhine): Non structural flood plain management. Measures and their effectiveness, International Commission for the Protection of the Rhine, Koblenz, 2002.

Krug, E. G., Kresnow, M.-J., Peddicord, J. P., Dahlberg, L. L., Powell, K. E., Crosby, A. E., and Annest, J. L.: Suicide after natural disasters, New Engl. J. Med., 338(6), 373–378, 1998.

Montz, B. E.: The effects of flooding on residential property values in three New Zealand communities, Disasters, 16, 283–298, 1992.

NRC (National Research Council): Risk analysis and uncertainty in flood damage reduction studies, National Academy Press, Washington D. C., 2000.

Olsen, J. R., Beling, P. A., Lambert, J. H., and Haimes, Y. V.: Input-output economic evaluation of system of levees, J. Water Res. Pl-ASCE, 9/10, 237–245, 1998.

Parker, D. J., Green, C. H., and Thompson, P. M.: Urban flood protection benefits: A project appraisal guide, Gower Technical Press, Aldershot, 1987.

Penning-Rowsell, E. C. and Chatterton, J. B.: The benefits of flood alleviation: A manual of assessment techniques, Gower Technical Press, Aldershot, 1977.

Penning-Rowsell, E. C. and Fordham, M.: Floods across Europe: Flood hazard assessment, modelling and management, Middlesex University Press, London, 1994.

Penning-Rowsell, E. C. and Green, C.: New Insights into the appraisal of flood-alleviation benefits: (1) Flood damage and flood loss information, J. Chart. Inst. Water E., 14, 347–353, 2000.

Penning-Rowsell, E. C., Fordham, M., Correia, F. N., Gardiner, J., Green, C., Hubert, G., Ketteridge, A.-M., Klaus, J., Parker, D., Peerbolte, B., Pflügner, W., Reitano, B., Rocha, J., Sanchez-Arcilla, A., Saraiva, M. d. G., Schmidtke, R., Torterotot, J.-P., Van der Veen, A., Wierstra, E., and Wind, H.: Flood hazard assessment, modelling and management: Results from the EUROflood project, in: Floods across Europe: Flood hazard assessment, modelling and management, edited by Penning-Rowsell, E. C. and Fordham, M., Middlesex University Press, London, 1994.

Peterman, R. M. and Anderson, J. L.: Decision analysis: a method for taking uncertainties into account in risk-based decision making, Hum. Ecol. Risk Assess., 5(2), 231–244, 1999.

Smith, D. I.: Flood damage estimation – A review of urban stage-damage curves and loss functions, Water SA, 20(3), 231–238, 1994.

Smith, K. and Ward, R.: Floods: Physical processes and human impacts, John Wiley and Sons, Chichester, 1998.

USACE (U.S. Army Corps of Engineers): Guidelines for risk and uncertainty analysis in water resources planning, Institute for Water Resources, IWR Report 92-R-1, Fort Belvoir, VA, 1992.

USACE (U.S. Army Corps of Engineers): Risk-based analysis for flood damage reduction studies, Engineering Manual 1110–2–1619, Washington D. C., 1996.

Wind, H. G., Nierop, T. M., de Blois, C. J., and de Kok, J. L.: Analysis of flood damages from the 1993 and 1995 Meuse floods, Water Resour. Res., 35(11), 3459–3465, 1999.