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METHODS FOR THE EVALUATION OF DIRECT AND INDIRECT FLOOD LOSSES

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ABSTRACT: The estimation of economic flood losses is a crucial part when decisions about flood defense are taken on the basis of cost-benefit-analyses. However, the field of flood loss modeling has not gained much attention so far. Therefore, improved and scientifically sound loss models are a fundamental step towards a cost-effective flood management. In the aftermath of floods in August 2002, August 2005 and April 2006 extensive datasets about flood losses were collected at affected properties in Germany. Together with other information these datasets were used within the project “Methods for the Evaluation of Direct and Indirect flood losses” (MEDIS) to derive multi-factorial loss models for the residential, commercial, agricultural and public sector. The aim was to improve the hitherto existing methods for flood loss estimation. Therefore, model development was accomplished by a thorough validation of the new loss models and by comparing their performance to currently used stage-damage-curves. To provide a consistent flood loss data base in the future the MEDIS project has also dealt with improvements of the collection of flood loss data. Therefore, a manual for harmonized loss data collection procedures has been developed. With this, a consistent basis for the development and continuous updating of loss models can be achieved.

Key Words: loss modeling; flood damage; data collection; model validation

1. INTRODUCTION

Risk mapping, (comparative) risk analyses, financial appraisals of probable (maximum) losses as well as risk-oriented flood design have been gaining more and more attention in the last years and require reliable estimations of flood losses. In engineering and technical assessments, risk is commonly defined as the damage that occurs or is exceeded with a certain probability. Risk encompasses two aspects:

hazard and vulnerability: While flood hazard assessments describe the intensity (e.g. extent and inundation depths) and probability of a flood scenario in a given region and timeframe, vulnerability analyses address the impacts of a flood. Currently, such analyses are often restricted to the quantification of direct, tangible losses and thus look at the elements that are exposed to the inundation and their susceptibility to the hydrological load.

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 affected building and the inundation depth at that building. These functions are an internationally accepted standard approach for assessing urban flood losses (Smith, 1994). Loss functions can provide the absolute loss in monetary values or the loss ratio, i.e. the percentage of the asset value that is damaged. In the latter case, the asset values of the exposed elements also have to be estimated in order to get loss information in monetary terms.

Current loss functions may have a large uncertainty (see Merz et al., 2004). One reason might be that flood loss is also influenced by other factors such as flow velocity, flood duration, contamination, building characteristics, private precautionary measures or flood warning (e.g., Smith, 1994; Penning-Rowsell, 1999; Kreibich et al., 2005; Thieken et al., 2005). These aspects are, however, neglected in most of the flood loss models. Furthermore, the reliability of flood loss and risk estimates is fairly unknown, since 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 (Dowton and Pielke, 2005).

To improve and validate the hitherto existing methods for flood loss estimation and loss data collection, the project “Methods for the Evaluation of Direct and Indirect flood losses” (MEDIS) was launched in 2005 within the framework of the German research program “Risk Management of Extreme Flood Events” (RIMAX). The project MEDIS targets the following topics:

- Evaluation of methods for the collection of flood loss data,
- Improvement of models for the estimation of direct and indirect flood losses,
- Model validation and application in water management as well as
- Improvement of knowledge transfer and risk communication.

Model development has been undertaken in several sectors, such as the residential, commercial, agricultural and public sector. This paper gives an overview of the most important results project.

2. ESTIMATION OF DIRECT FLOOD LOSSES - MODEL DEVELOPEMENT AND EVALUATION

In the aftermath of flooding in August 2002, August 2005 and April 2006 large datasets about flood losses and influencing factors were collected by computer-aided telephone interviews in private households and companies (e.g. Thieken et al., 2005; Kreibich et al., 2007). Together with data from field surveys, in which the damage to public infrastructure and the structural building were assessed, the experiences and data from the recent flood events were used to derive and evaluate new loss models for different sectors.

2.1 Residential sector

Losses to buildings and contents in the residential sector are estimated by the new model FLEMOps – the *F*lood *L*oss *E*stimation *MO*del for the *p*rivate *s*ector. The model is based on empirical data from 1697 private households in the German states Saxony, Saxony-Anhalt and Bavaria that were affected by a severe flood in August 2002.

In two model stages, five factors can be considered for loss estimations with FLEMOps (see Büchele et al., 2006 for details). In a core model, losses are estimated according to the water level, building type and building quality. The model distinguishes loss ratios for five classes of water levels, three building types and two classes of building quality. In all sub-categories mean loss ratios per loss type (building, contents) were derived from the empirical data. The model for building losses is illustrated in Fig. 1. While the loss ratios for shallow water levels, e.g. for < 21 cm above the ground surface, are comparable for all three building types, big differences occur for water levels of more than 100 cm (Fig. 1). This is due to the fact that in comparison to a one-family house still a small fraction of the asset value of a multifamily house is affected by flooding.

In a second model stage (further called FLEMOps+), the effects of private precautionary measures as well as of the contamination of the floodwater can be considered by scaling factors that are summarized in Table 1. Very good precaution can reduce building loss to 41%, while heavy contamination augments it by 58%.

The model FLEMOps can be applied to the micro-scale, i.e. to single buildings as well as to the meso-scale, i.e. land use units. For the latter, a scaling procedure based on census data and a dasymetric mapping technique was developed for the whole of Germany as is described by Thieken et al. (2008). In addition, a country-wide data base with the assets of residential buildings in all German municipalities is available for flood loss estimations in the whole of Germany (Kleist et al., 2006).

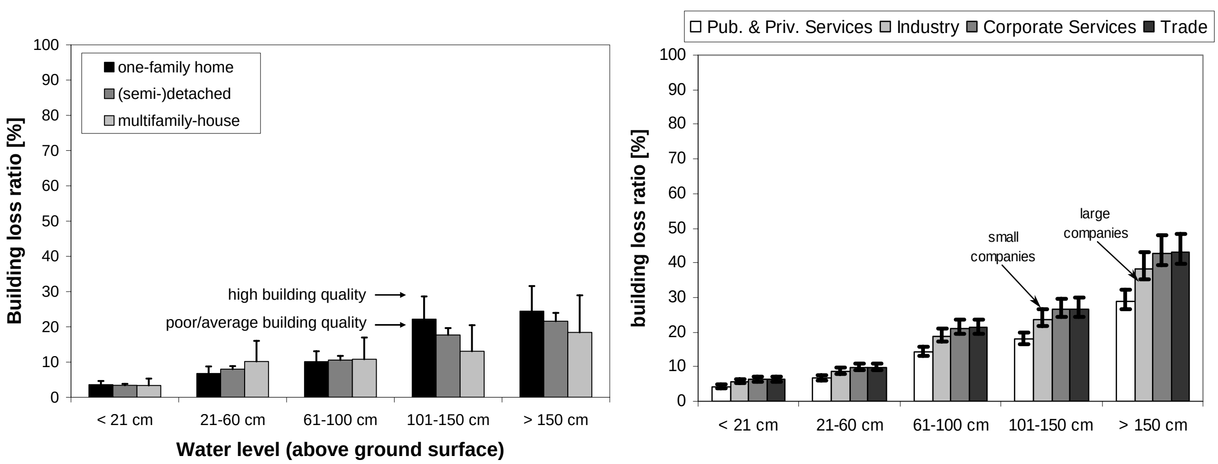

Figure 1: Micro-scale models for the estimation of flood losses to private buildings (FLEMOps; left) and commercial buildings (FLEMOcs, right) considering water level, building type/business sector and building quality/company size.

Table 1: Scaling factors for contamination of the floodwater and private precautionary measures to adapt losses to private buildings (FLEMOps) and commercial buildings (FLEMOcs).

Scaling factors for loss ratios of:	Private buildings	Commercial buildings
No contamination, no precaution	0.92	1.02
No contamination, medium precaution	0.64	0.82
No contamination, very good precaution	0.41	0.67
Medium contamination, no precaution	1.20	1.28
Medium contamination, medium precaution	0.86	1.03
Medium contamination, very good precaution	0.71	0.84
High contamination, no precaution	1.58	1.28
High contamination, medium precaution	---	1.03
High contamination, very good precaution	---	0.84

For the flood in 2002, meso-scale validations show that the new model outperforms other loss models currently used in Germany. However, when applied to other flood events FLEMOps tends to overestimate the losses (Thieken et al., 2008). Therefore, future research includes investigations of the influence of the affected region, the return periods of flooding and the flood type on the amount of loss.

2.2 Commercial and industrial sector (including public services)

The new *F*lood *L*oss *E*stimation *MO*del for the *c*ommercial *s*ector (FLEMOcs) was developed on the basis of detailed analyses of the flood loss datasets gathered after the 2002, 2005 and 2006 floods in Germany (e.g. Kreibich et al., 2007). Like FLEMOps, FLEMOcs was designed to work in two stages (Kreibich et al., submitted). In the first stage, the water depth divided into five classes (<21 cm, 21-60 cm, 61-100 cm, 101-150 cm, >150 cm), three sizes of companies in respect to the number of their employees (1-10, 11-100, >100 employees) and four different economic sectors (public and private services, producing industry, corporate services, trade) are taken into consideration. The results of this first stage are mean loss ratios for buildings (Fig. 1), equipment and goods, products and stock. In an optional second model stage, the different possible combinations of contamination and precaution can be taken into consideration, if the necessary information is available. The estimated loss ratios of the first stage are multiplied with the respective scaling factors (Tab. 1).

For a micro-scale application of the model, the appropriate classes have to be identified for each affected company. For instance, for a small company with two employees from the trade sector, which was affected by a water level of 15 cm, a loss ratio for the building of 7% is estimated (Fig. 1). The occurrence of heavy contamination without any precautionary measures would increase this ratio by 28%. No contamination and good precaution would result in a reduction of 33% (Tab. 1). The model can be applied to the micro-scale, i.e. to single buildings as well as to the meso-scale, i.e. land use units, which enables its countrywide application.

For the estimation of absolute losses it is necessary to combine the relative loss ratios of the model with data on the asset values of the companies. Therefore an asset value database for the whole of Germany was created combining macroeconomic data from the Federal Statistical Office Germany and the Federal Employment Agency with geomarketing data (Seifert et al., submitted). For loss modelling and risk analyses, the provision of exposure data at the municipal level is not sufficient. Therefore, the municipal asset estimates have to be further disaggregated on the basis of realistic assumptions and dasymetric mapping techniques. As in the residential sector CORINE land cover data (CLC2000) and the mapping technique of Mennis (2003) were adapted for the meso-scale loss modelling with FLEMOcs (Kreibich et al., submitted).

The micro-scale leave-one-out cross validation shows very good results with no bias and mean absolute errors between 23% and 31%. Additionally, it reveals that it is worthwhile to improve the model, especially with an emphasis on low water depths (Kreibich et al., submitted). The meso-scale validation indicates that in contrast to other so far used models there is no systematic error. However, further validation including more test sites is needed.

2.3 Agricultural sector

Flood damage in the agricultural sector can be classified into the following categories:

- damage on agricultural land, particularly crop loss and adverse effects on plant growth,
- damage to buildings, machinery and equipment,
- damage to stocks or means of production (feeding stuff, fertilizer, seeds),
- costs for evacuation (e.g. of livestock) and
- other costs (e.g. clearing and cleaning-up costs, costs for repairing damaged agricultural infrastructure such as farm tracks or drainage systems).

Due to the fact that agricultural plots are located right in the vicinity of rivers and creeks, adverse effects on plant growth and crop losses are the most important damage category. Therefore, a new model was created within the scope of the MEDIS-Project for this type of loss. The model considers four influencing factors:

- seasonality of the flood event (per month)
- crop type (potatoes, sugar beets, corn, winter wheat, winter barley, winter rye, canola and grassland)
- region (38 rural districts in Germany)
- inundation duration (in four classes, i.e. 1-3 days, 4-7 days, 8-11 days, >11 days)

Crop loss is calculated as a percental deduction of the perennial averaged yields and is measured in Euro per hectare. The model focuses only on the economic component of revenues (i.e. the yield multiplied by the sales price). In a first modelling step the perennial averaged yields of a particular crop in the region under study are determined with the help of data provided by the KTBL (see http://www.ktbl.de/index.php?id=359). As a second step they are charged against the percental deductions depending on the seasonality of the flood event, the inundation duration and the affected crop type. The result is the estimated loss for the investigated acreage in Euro per hectare. In this way it is possible to give a rough appraisal of the expected crop losses for particular regions or boundaries in agriculture in conjunction with cultivation plans and seasonable occurrence probabilities of flood incidents. Using data from a municipality where the flood of the river Elbe in 2002 caused agricultural losses of 644000 Euro, Förster et al. (2008) showed that the new model is capable of estimating a realistic amount of crop losses – in case of the selected municipality 546000 Euro.

2.4 Transportation

While the use of damage functions is an established approach for the estimation of flood losses in the residential, commercial and - to some extent - in the agricultural sector, the authors are not aware of similar empirically-based methods for the estimation of direct losses with regard to transportation infrastructure. Within the scope of the MEDIS project, research was focused on direct losses to roads. In a first step, a database was constructed that contained information about road characteristics, characteristics of the hydrological load and repair costs associated to the inundation. For this, information filed by the city of Dresden for the management of reconstruction projects in the aftermath of the 2002 flood was provided and supplemented with hydraulic modeling results and experts judgment. Damage was measured with four variables: (1) as monetary reconstruction costs per square meter, (2) as the relative loss compared to an estimated replacement value of road section under study and (3) compared to its estimated current value, and finally (4) on a six point damage scale as reported by the experts of the city administration. In addition, the criteria “road type” and “pre-flood condition of the road section” were recorded and analyzed in relation to the damage that had occurred.

To cover effects of different flood characteristics two distinctively different parts within the city of Dresden were investigated. The city centre was mainly affected by the river Elbe and partly by a tributary, the river Weisseritz, while the second part was inundated by the river Lockwitz with a fast flood reaction. Altogether, detailed information on approximately 300 road sections was compiled representing a monetary reconstruction volume of 43 Million Euro.

Tentative results of regression analyses show a weak influence of inundation depth and a significant influence of flood velocity on the damage as measured by variable (4). It appears that there is no effect of the pre-flood condition of the road on the extent of the damage. Thus, it has to be concluded that the monetary damage assessments are distorted by the varying extents of the reconstruction projects, as they may include substantial upgrading or modernization of the assets.

3. APPROACHES FOR THE ASSESSMENT OF INDIRECT FLOOD LOSSES

While direct flood damage occur due to the physical contact of objects with the flood water, indirect damage is induced by flooding, but occurs - in space or time - outside the actual event. To illustrate the spatial and temporal dimension of direct and indirect tangible losses, space-time diagrams were developed as shown in Fig. 2. In accordance with other authors (e.g. van der Veen et al., 2003) all expenses for disaster response (e.g. costs for sandbagging, evacuation) were classified as indirect damage (Fig. 2). Within the MEDIS project, data and models for the assessment of disaster response were further investigated.

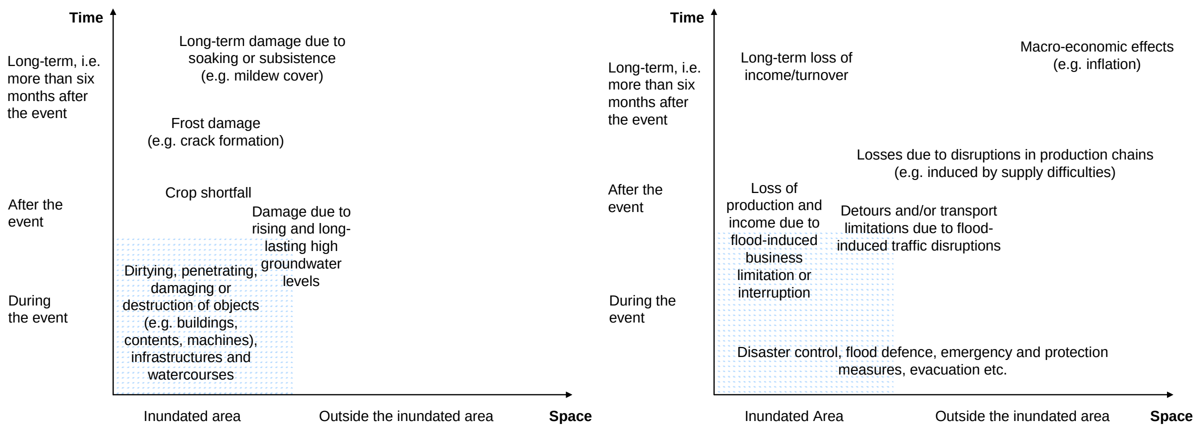

Figure 2: Direct (left) and indirect (right) tangible flood losses and their spatial and temporal occurrence (The shaded area indicates the inundated area and the time of flooding).

Costs for emergency services, evacuation, securing infrastructure and clean-up can be substantial. In the case of Hurricane Katrina the approved government expenditure for emergency services amounted to more than US$ 5 billion which equaled 3.7 per cent of the total economic loss of this event. Even higher shares of spending have been reported in Europe (Penning-Rowsell and Wilson, 2006).

Within the MEDIS project, a regression analysis of the 2005 flood event in Tyrol/Austria was undertaken to identify the drivers of the costs of emergency services and clean up. The main results are reported in Pfurtscheller and Schwarze (2008). According to this study, local characteristics, the intensity and duration of flooding and the coincidence of multiple hazards prove to be the most significant factors. Emergency costs depict a non-linear relationship to the sum of damages so that average values as suggested by Penning-Rowsell and Wilson (2006) can be misleading.

4. TOWARDS A STANDARDIZED COLLECTION OF FLOOD LOSSES

4.1 Standardized attributes for loss data collection

The documentation of losses caused by severe flooding in 2002 and 2005 in Germany as well as in other European countries revealed that flood loss data are commonly collected for a specific purpose (e.g. claims settlement, flood damage analysis for planning or scientific purposes). Thus, datasets differ in type and amount of recorded attributes. For example, insurance companies mainly focus on the collection of the monetary losses (repair costs) and their relation to the total insured value of the damaged object, while datasets that were gathered with the aim to classify structural damage or to derive loss estimation models also contain information about the flood characteristics, building types, construction material etc. In order to allow multi-purpose use of flood loss datasets general standards for the collection of damage data were developed for different five damage sectors, i.e. the residential, commercial (including industrial sites and public infrastructure except for transportation) and agricultural sector as well as transportation and water management (including damage to water courses and flood defense).

Standards for flood damage assessment and flood loss data collection should contain a basic set of attributes that are indispensable for loss analysis. To develop such a set of criteria, information needs in different fields of flood damage analysis have to be identified. For this purpose a multi-step online survey was conducted using the Delphi-approach with a panel of 55 experts from (re-)insurances, engineering companies, public water agencies and scientific institutions. The survey covered the five damage sectors mentioned above. The core part of the survey consisted of questions addressing the importance of a wide range of criteria for flood loss analysis that were to be evaluated by the experts on a rank scale from 1 (information is very important) to 6 (information is useless).

There was a level of congruence in information needs between experts with different professional backgrounds that allowed the development of a single set with basic damage assessment standards for each sector. Within the MEDIS-project all core attributes per sector were grouped into four main categories, i.e. flood characteristics, object characteristics, damage information and information about damage reduction, as shown in Fig. 3 for the residential sector.

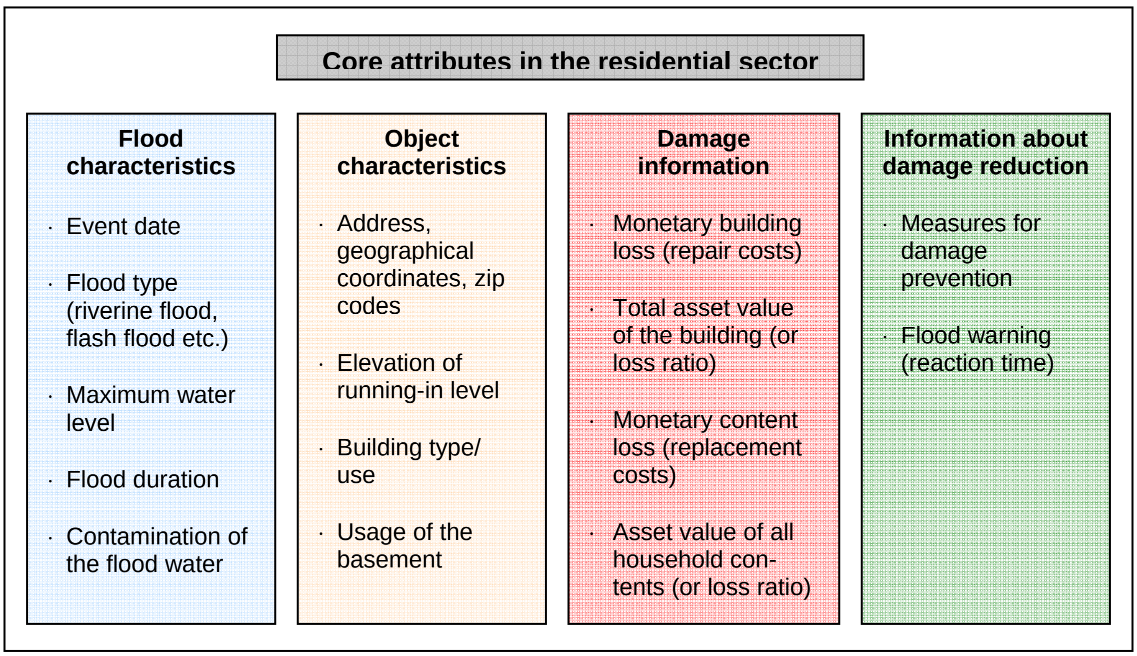

Figure 3: Core attributes for collection of damage data in the residential sector.

On the basis of the expert survey, a manual for data collection in the five damage sectors has been compiled (Thieken et al., 2008b). The manual outlines the theoretical framework for flood loss assessment and suggests criteria for loss documentation. For the latter, the core attributes for each sector were supplemented by evaluation methodologies (e.g. measurement units, check lists). In addition, suggestions for meta-data, general event documentation and aggregated damage reports are presented.

4.2 Framework for assessing structural building damage

As a further part of the project a method for the classification and determination of structural building damage has been developed. In this context, the detailed survey and the standardized documentation of damage cases provide the initial step to reflect the vulnerability of building types. As a whole, two basic datasets were considered within the framework of the MEDIS project:

- Dataset 1 (“EDAC“): Data were elaborated by field surveys immediately after the August 2002 flood and by written questionnaires in 2003 and 2004. Damage cases were related to the building being particularly affected; e.g. moderate and higher damage grades were dominating. Repeatedly observed damage patterns were transformed into a classification scheme of damage grades (see Schwarz and Maiwald, 2008)
- Dataset 2 (“MEDIS”): Data were gathered by computer-aided telephone interviews with building owners after two moderate floods in Bavaria 2005 and in Saxony 2006 (see also section 2.1).

The datasets include information about duration, velocity (qualitatively) and other secondary (probably damage contributing) flood action as well as vulnerability-related parameters. The data were unified with respect to structural parameters. Verbal damage descriptions were transferred into damage grades ranging from 1 (moisture penetration) to 5 (building collapse).

On this basis a new type of vulnerability functions can be presented, which enable a differentiation with respect to the main structural (wall) material (Figure 4). As is shown in Schwarz and Maiwald (2008), the methodology enables the reinterpretation of damage with respect to structural damage and monetary loss. Furthermore, local areas with higher vulnerability of the building stock can be identified (see Schwarz and Maiwald, 2008, for details).

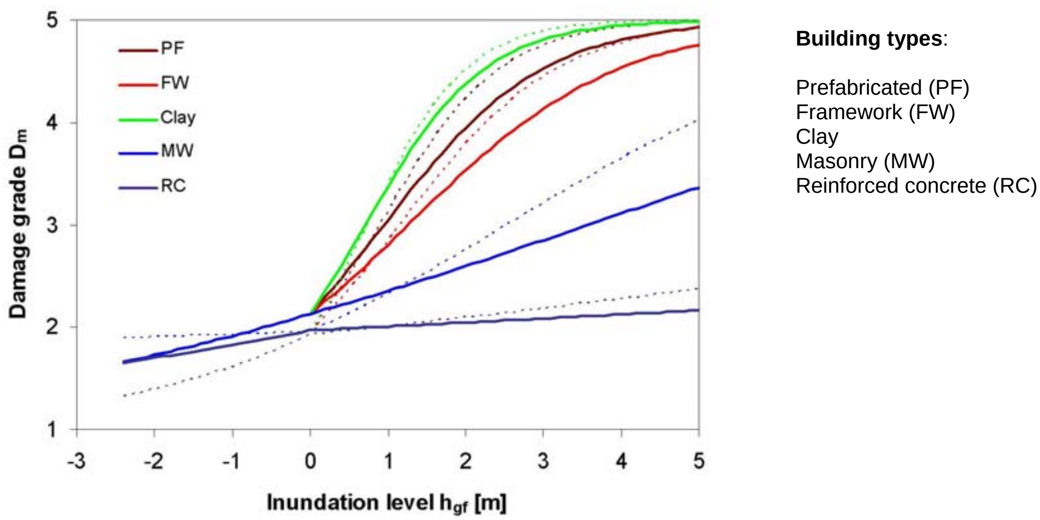

Figure 4. Vulnerability functions of type $D_m = f(h_{gf})$; derived for dataset “1” (broken lines) and combined dataset “1+2” (thick lines)

5. CONCLUSIONS

New models that consider not only the water level, but also additional factors like contamination, building material or flood duration were developed for the estimation of structural damage and monetary losses in the residential, commercial and agricultural sector. First validations show that the new models outperform loss functions currently used in Germany. Future work should include further model evaluations including more test sites covering a variety of regions and flood patterns.

With regard to the transportation sector as well as in the field of indirect losses up-to-date and unique datasets were gathered. First data analyses revealed the most important factors that should be included in loss modeling in the future.

As a consequence of the experiences made during the model developments and of a large survey among flood damage experts, catalogues for a standardized collection of loss data were complied for different damage sectors. For a transfer into practice further efforts have to be made concerning the development of software tools ensuring standardized procedures, check lists etc..

6. ACKNOWLEDGEMENTS

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