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 of 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 for 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 [1]. However, loss functions may have a large uncertainty (see [2]), 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. 1, 3–5]. 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 [6]. Low standardization 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 [7].

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 [4] and [5]. For example, the total asset values of the affected buildings were estimated according to the VdS guideline 772 1988-10 [8]. 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 [5] 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 ***F***lood ***L***oss ***E***stimation ***MO***del for the ***p***rivate ***s***ector (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.

Table 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

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.

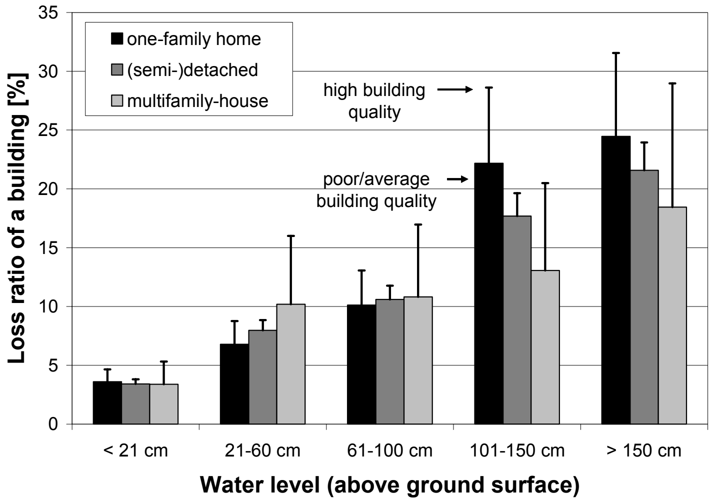

Figure 1: Micro-scale FLEMOps model for the estimation of flood losses to residential buildings considering water level, building type and building quality; derived from data of 1697 households affected by the August 2002 flood (adapted from [9]).

Table 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 [9]).

	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

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 [10] 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 [11]. The adaptation of this method for loss modelling was demonstrated by [12].

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

Cluster	Share EFH (%)	Share RDH (%)	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 RDH)
4	68.51	21.43	10.05	Mixed (high share of EFH)
5	92.25	4.81	2.94	Dominated by one-family homes
all	73.20	14.30	12.50	Mean composition

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 summarized 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.

3.1.1 Input data

In three affected municipalities in Saxony, records of eligible repair costs, which almost represent the building loss, were provided by the Saxonian Relief Bank (Sächsische Aufbaubank – SAB) and were combined with information about building types and observed and/or simulated water depths at the buildings by [13]. The mean asset value per building type and municipality was taken from the work of [14], the level of contamination and precaution was derived from the telephone interviews described in section 2.1.

3.1.2 Results and discussion

The total and mean building loss estimates in the three municipalities are summarized in Tab. 5. 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. 5 shows that FLEMOps+ performs well with observed water levels, but fails in some cases with simulated water levels.

To get an idea about the weaknesses of the model, model performance was analyzed in different classes of water levels and flow velocities. Fig. 3 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 Saxonian municipalities that were affected by the flood in August 2002 as well as to five municipalities in Baden-Wuerttemberg that

Table 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 evalua-tion
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 Saxonian Dam Authority)	47.75	138393	+

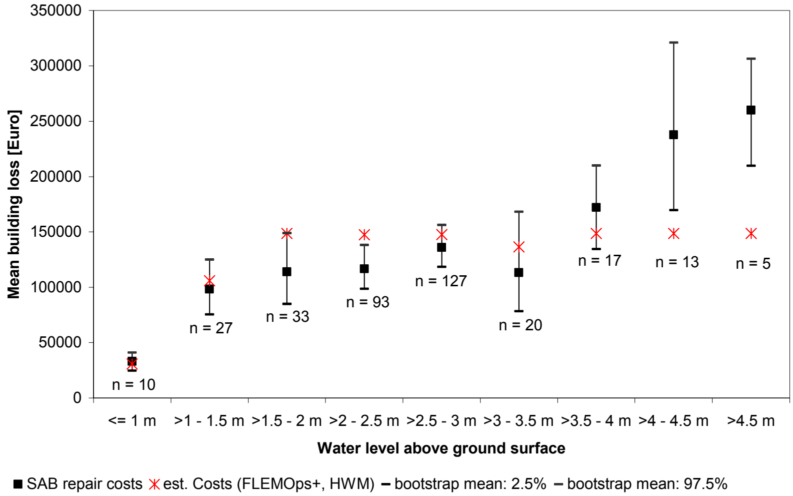

Figure 2: Performance of the model FLEMOps+ in different water level classes using 345 loss records from the municipality of Grimma.

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 [15]. 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 [16]. 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 [17].

3.2.1 Input data

The August 2002 flood event was simulated by the 1D/2D-model LISFLOOD-FP [18] 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 [19]. 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 [12] 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.

3.2.2 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 [20] for further details). Therefore, the regional validity of loss models has to be investigated further.

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 analyzed. From the surveyed data, the new Flood Loss Estimation Model for the private

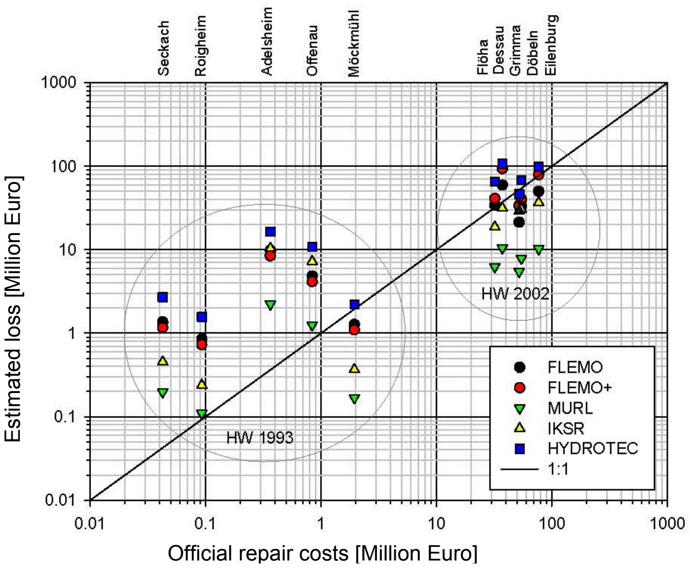

Figure 3: Official repair costs and estimated building losses in ten municipalities that were affected by flooding in 1993 or in 2002.

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.

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