



# Up-scaling of multi-variable flood loss models from objects to land use units at the meso-scale

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**Abstract.** Flood risk management increasingly relies on risk analyses, including loss modelling. Most of the flood loss models usually applied in standard practice have in common that complex damaging processes are described by simple approaches like stage-damage functions. Novel multi-variable models significantly improve loss estimation on the micro-scale and may also be advantageous for large-scale applications. However, more input parameters also reveal additional uncertainty, even more in upscaling procedures for meso-scale applications, where the parameters need to be estimated on a regional area-wide basis.

To gain more knowledge about challenges associated with the up-scaling of multi-variable flood loss models the following approach is applied: Single- and multi-variable micro-scale flood loss models are up-scaled and applied on the meso-scale, namely on basis of ATKIS land-use units. Application and validation is undertaken in 19 municipalities, which were affected during the 2002 flood by the River Mulde in Saxony, Germany by comparison to official loss data provided by the Saxon Relief Bank (SAB).

In the meso-scale case study based model validation, most multi-variable models show smaller errors than the uni-variable stage-damage functions. The results show the suitability of the up-scaling approach, and, in accordance with micro-scale validation studies, that multi-variable models are an improvement in flood loss modelling also on the meso-scale. However, uncertainties remain high, stressing the importance of uncertainty quantification. Thus, the development of probabilistic loss models, like BT-FLEMO used in this study, which inherently provide uncertainty information are the way forward.

## 1 Introduction

Losses from natural disasters have dramatically increased during the last few decades and floods have generated the largest economic losses, also in Germany (Kreibich et al., 2014). Flood risk analyses are gaining more and more attention in the fields of flood design, prevention, and risk-management (EU flood risk directive 2007/60/EC). Flood risk analyses are performed on different spatial scales (Meyer and Messner, 2005; de Moel et al., 2015): At the micro-scale the assessment is based on single elements at risk. For instance, in order to estimate the loss to a community in case of a certain flood scenario, loss is calculated for each affected object (e.g. building). At the meso-scale the assessment is based on spatial aggregations. Typical aggregation units are land use units, e.g. residential areas. At the macro-scale large-scale spatial units are the basis for loss estimation.

Typically, administrative units are used, e.g. municipalities, regions, countries. The classification in micro-, meso- and macro-scale is, on the one hand, related to the spatial extent of the loss assessment. On the other hand, there is a methodological distinction: Meso- and macro-scale approaches differ from micro-scale approaches in their need for aggregation. Loss is assessed for aggregated objects, e.g. land use units. Commonly a bottom-up approach is used, which starts with a detailed analysis and modelling of single elements at risk (micro-scale) and develops an up-scaling procedure for application on basis of land-use units (e.g. Kreibich et al., 2010).

The objective of this study is to gain additional knowledge about challenges associated with the up-scaling of flood loss models, particularly multi-variable loss models. Single- and multi-variable flood loss models are up-scaled to be applied

on the meso-scale in a test area. Validation is undertaken via comparisons with official loss data.

## 2 Loss models

The following seven loss models, which estimate direct economic loss to residential buildings, are up-scaled to be used at the meso-scale.

The probabilistic, multi-variable model BT-FLEMO developed by Merz et al. (2013) is an ensemble of 200 regression trees, which use the following predictors: water depth, return period, contamination indicator, inundation duration, flow velocity indicator, floor space of building, building value and precautionary measures indicator.

The rule based FLEMOps+r model (Elmer et al., 2010) calculates flood loss using five different classes of water depth, three individual building types, two classes of building quality and three classes of return period (Fig. 1).

The regression tree loss model (RT2) developed by Merz et al. (2013) has eight leaves using the predictors water depth, floor space of building, return period, monthly net income of the household.

The stage-damage function of MURL (2000) calculates the loss ratio (rloss [-]) of residential buildings by the equation  $rloss = 0.02 wst$ , where  $wst$  is the water depth [m]. For water levels of more than 5 m the loss ratio is set to 0.1 (Fig. 1).

The stage-damage function of ICPR (2001) estimates the loss ratios of residential buildings by the relation  $rloss = (2 wst^2 + 2 wst)/100$ . Estimated loss ratios  $> 1$  are set to 1, i.e. total loss (Fig. 1).

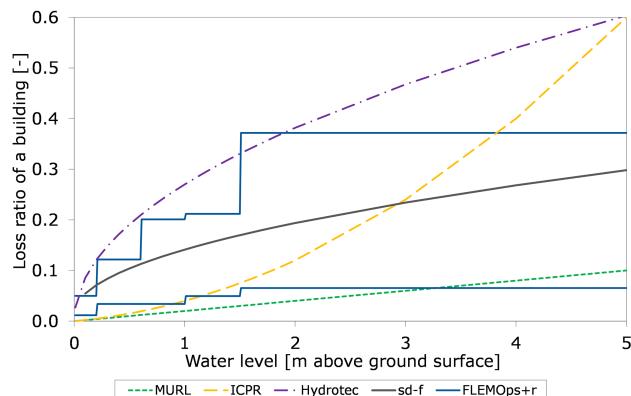
The stage-damage function of HYDROTEC (2001, 2002) uses the root function  $rloss = (27\sqrt{wst})/100$ . Estimated loss ratios  $> 1$  are set to 1 (Fig. 1).

The stage-damage function sd-f is taken from Merz et al. (2013) and uses the equation  $rloss = 0.0142 + 0.0127 \times \sqrt{wst \times 100}$  (Fig. 1).

## 3 Up-scaling approach

The up-scaling approach of Kreibich et al. (2010) is followed, i.e. the model structures are not changed, but the input variables of the micro-scale loss models are estimated area-wide for spatially aggregated meso-scale units. The following data is used to estimate the model-input variables for the test area, i.e. 19 municipalities that were affected by the 2002 flood at the river Mulde in Saxony, Germany.

The inundation patterns including water depths distribution of the 2002 flood in the 19 case study municipalities are taken from Grabbert (2006) and Apel et al. (2007). Return periods are taken from Elmer et al. (2010). Contamination indicator, inundation duration, flow velocity indicator, precautionary measures indicator and monthly net income are estimated on basis of empirical flood damage data collected



**Figure 1.** Stage-damage functions as well as upper and lower bounds of the rule based multi-variable model FLEMOps+r used in this up-scaling study.

via computer aided telephone interviews with households affected by the 2002 flood in the case study area (Thieken et al., 2005). The average floor space of residential buildings as well as the average building value per municipality are taken from the Germany-wide exposure dataset of Kleist et al. (2006). The residential building type composition and the mean residential building quality per municipality are derived following the approach of Thieken et al. (2008).

These meso-scale input variables are estimated on the municipal level, except for water depth and return period, which are given, in a more spatially differentiated format. Water depth is modeled area-wide with 10 m grid resolution. Return periods are estimated on sub-catchment level. All input variables are processed to be available as raster data sets with a cell size of 10 m  $\times$  10 m. For each grid cell, the loss ratio is estimated by applying the seven loss models on basis of the meso-scale input variables. These loss ratios are then multiplied by the specific building value assigned to the corresponding grid cell. Finally, the loss estimates are aggregated per municipality. The specific building values were extracted from Wünsch et al. (2009).

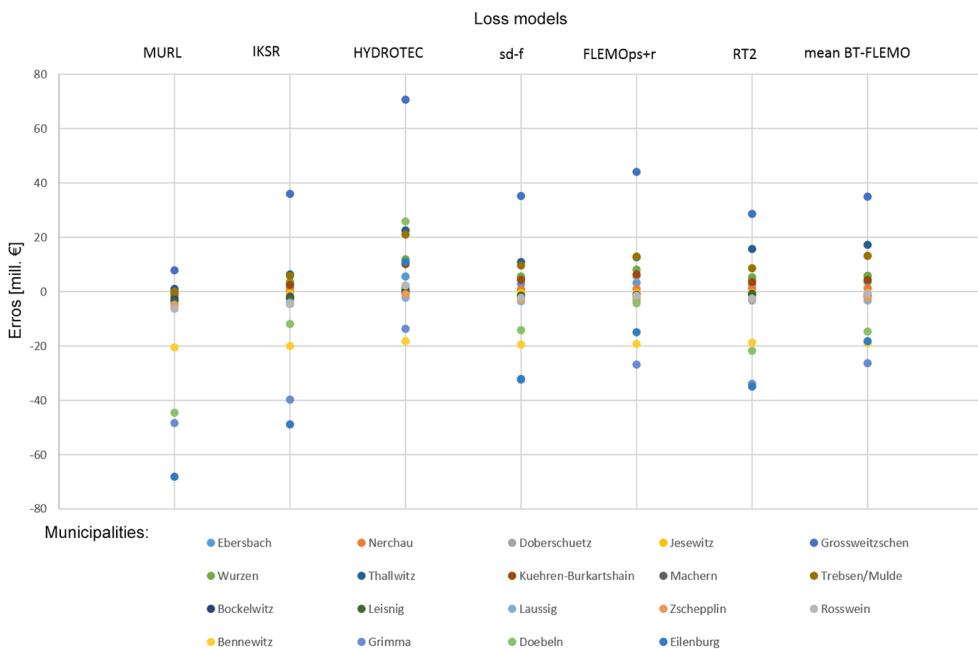
## 4 Application and Validation

Meso-scale model application and validation are conducted in 19 municipalities located at the river Mulde in Saxony, Germany. The area was strongly affected by the 2002 flood. Flood loss was well documented by the Saxon Relief Bank, which was in charge of the loss adjustment and management in Saxony after the flood in 2002.

The above listed seven loss models are used to estimate direct economic losses of residential buildings for the 19 municipalities of the case study area. The modelled aggregated absolute loss to residential buildings per municipality is compared to the official loss information provided by the Saxon Relief Bank (2005).

**Table 1.** Error statistics of meso-scale model performance (MBE: mean bias error, MAE: mean absolute error).

	MURL	ICPR	HYDROTEC	sd-f	FLEMOps+r	RT2	BT-FLEMO
MBE [Mill. €]	-10.4	-4.2	8.4	-2.0	0.9	-2.6	-0.1
MAE [mill. €]	11.5	10.5	12.1	9.8	9.0	10.1	9.2

**Figure 2.** Errors, i.e. estimated loss minus officially reported loss [million euros] for all tested models and municipalities.

## 5 Results and Discussion

The two best performing models in terms of mean absolute error are the multi-variable models FLEMOps+r and BT-FLEMO (Table 1). BT-FLEMO additionally provides a nearly unbiased prediction. The models which were developed on basis of empirical loss data from recent flood events in 2002, 2005 and 2006, namely sd-f, FLEMOps+r, RT2 and BT-FLEMO, perform better than the other models MURL, ICPR, and HYDROTEC which were developed on basis of expert judgement and loss data from floods between 1978 and 1994.

Multi-variable models outperform stage-damage functions and are as such an improvement in flood loss modelling also on the meso-scale. However, the model sd-f with one input variable shows in comparison still relatively good error statistics (Table 1), and is as such also suitable for meso-scale loss estimation. Uncertainties of loss estimation remain high, which underlines the importance of uncertainty quantification. The probabilistic loss model BT-FLEMO is as such a significant advancement.

The error statistics are strongly influenced by five municipalities, which appear particularly problematic for loss es-

timation (Fig. 2): Bennewitz, Eilenburg, Grimma and Döbeln where most models underestimate the loss as well as Grossweitzschen where all models overestimate the loss. The different loss models provide coherent results in terms of underestimation in some municipalities and overestimation in others. The within model variation of loss predictions are smaller than within municipalities (Fig. 2). Seifert et al. (2010) reported similar patterns for loss estimation for the commercial sector. They relate large errors in loss estimation to high uncertainties in the exposure estimation, particularly in municipalities with a small fraction of affected companies. This is in accordance with the presented results: smaller errors in loss estimation are obtained for municipalities which incurred larger total loss in comparison to municipalities which incurred a total loss below about EUR 3 million officially reported loss (exception is Bennewitz).

## 6 Conclusions

Multi-variable models outperform stage-damage functions and are as such an improvement in flood loss modelling also on the meso-scale. However, more input variables also reveal additional uncertainty, even more in up-scaling proce-

dures, where the model input variables are estimated on a regional area-wide basis. Hence, a suitable compromise between model performance and number of variables should be aimed for. Further research should develop more spatially differentiated estimation methods for key input variables used in flood loss estimation at the meso-scale. The use of remote sensing data is a way forward in this respect (Gerl et al., 2014). This study shows that uncertainties of loss estimation remain high. Therefore, thorough validations and uncertainty analyses are necessary for the development of reliable loss models as a basis for application in flood risk studies. The development of probabilistic loss models, possibly with less input variables for an easier meso-scale application, is the way forward.

In municipalities where all loss models significantly over- or underestimate the official loss report it is likely that errors and uncertainty result from other sources along the loss estimation chain, e.g. from inundation modelling or exposure estimation. A further source is the uncertainty of the official loss data. These other sources of uncertainty are not addressed in this study. However, comprehensive uncertainty analyses including all components of the flood risk model chain, as for instance undertaken by Apel et al. (2009), should be further developed.

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