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# Application and validation of FLEMOcs – a flood loss estimation model for the commercial sector

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**Abstract** The estimation of flood losses is difficult, especially in the commercial sector because of its great inhomogeneity. However, the reliability of loss modelling is fairly unknown, since flood loss models are scarcely validated. The newly developed Flood Loss Estimation MOdel for the commercial sector (FLEMOcs) was validated on the micro-scale using a leave-one-out cross validation procedure. Additionally, different meso-scale loss functions were compared. Meso-scale model application was undertaken in 19 municipalities which were affected during the 2002 flood in Germany. Model results were compared with the results of three other loss models, as well as with official loss records. The micro-scale validation shows very good results with no bias and mean absolute errors between 23% and 31%. The meso-scale validation indicates that FLEMOcs provides good results especially in large areas with many affected companies where high losses are expected.

**Key words** flood loss model; stage-damage curves; model comparison; validation; Germany

## Titre

**Résumé**

**Mots clefs**

## 1 INTRODUCTION

For flood loss modelling, the processes causing flood losses are represented by stage-damage curves i.e. the impact of the flood hazard on the assets is described with mathematical functions (Parker et. al., 1987; Smith, 1994; Dutta et al., 2003; Penning-Rowsell et. al., 2005a; b; Scawthorn et. al., 2006). Linking the information on flooding characteristics, assets and the damage-process allows the estimation of flood losses for given flood scenarios.

Loss models for the commercial sector were developed in and outside Germany (NRE, 2000; MURL, 2000; ICPR, 2001; NR&M, 2002; FEMA, 2003; Emschergenossenschaft and Hydrotec, 2004; Penning-Rowsell et al., 2005a, b; LfUG, 2005; Scawthorn et al., 2006). They are described in detail in Kreibich et al. (2010) along with the newly developed model FLEMOcs (Flood Loss Estimation MOdel for the commercial sector). FLEMOcs estimates losses to buildings, equipment and goods, products, and stock of companies. In a first model stage it considers the water depth, the size of companies in terms of the number of employees and the sector. In the second model stage, the effects of precaution and contamination can be taken into account. The model can be applied to the micro-scale, i.e. to single production sites as well as to the meso-scale, i.e. land use units, which enables its countrywide application (Kreibich et al., 2010). It was derived from object-specific empirical data from three recent floods in 2002, 2005 and 2006 in Germany (Kreibich et al., 2007).

The estimation of flood losses is difficult, especially in the commercial sector, because of its great inhomogeneity and insufficient loss data (Ramirez et al., 1988; Gissing and Blong, 2004). The reliability of loss modelling is fairly unknown, since flood loss models are scarcely validated. This might be due to a lack of adequate data from extreme flood events. Especially, damage data are rarely gathered, (initial) repair cost estimates are uncertain and data are not updated systematically (Downton and Pielke, 2005).

The objective of this study is the application and validation of FLEMOcs (Kreibich et al., 2010). On the micro-scale it is validated using a leave-one-out cross validation procedure. Meso-scale model application is undertaken in 19 municipalities which were affected during the 2002 flood in Germany. Model results are compared with the results of other loss models, and official loss records.

## 2 METHODS

For model validation on the micro scale, a leave-one-out cross validation procedure (e.g. Davis, 1987) based on empirical data from three recent floods in 2002, 2005 and 2006 in Germany (Kreibich et al., 2007; 2010) was applied as follows. One after another, each data point was singled out, then the FLEMOcs model functions were derived on basis of the remaining data and finally, the loss ratios of the singled out data point were estimated using the FLEMOcs model developed without it. As such, flood loss ratios were estimated for all interviewed companies for which sufficient information was available. The errors of the model estimates were evaluated by their mean bias error (MBE), mean absolute error (MAE) and root mean square error (RMSE). MBE provides the average deviation of the modelled values from the interviewed values, i.e. it indicates an average bias of the model. A positive MBE signifies an overestimation in the modelled values while a negative MBE represents an underestimation. MAE provides the average absolute deviation of the modelled values from the interviewed values, whereas the RMSE provides information on the variation of the modelled values from the interviewed values. As the square root of a variance, RMSE can be interpreted as the standard deviation of the unexplained variance, and has the property of being in the same unit as the modelled variable. Additionally, the ordinary bootstrap approach was applied (Efron, 1979). The companies were grouped according to sectors and water depth class and confidence intervals for their mean loss ratios were calculated on the basis of 10000 simulated random samples of loss data which were drawn with replacement (bootstrap). The model performance was judged as sufficiently accurate, if the estimated mean loss ratios were within the 2.5%-97.5% confidence interval.

For model evaluation on the meso-scale, FLEMOcs is compared with three other relative, meso-scale loss functions commonly used in Germany: MURL (MURL, 2000), ICPR (ICPR,

2001) and Hydrotec (Emschergenossenschaft and Hydrotec, 2004). FLEMOcs as well as the other models are applied to estimate flood losses in 19 municipalities in Saxony, Germany.

As hazard scenario the flood event of August 2002 in the Elbe river and its tributaries was chosen. In most municipalities water depths were derived via hydraulic transformation (Grabbert, 2006). In Dresden water levels were intersected with a digital elevation model and the maximum water level at the gauge in Dresden was interpolated. These data were provided by Grabbert (2006). In Döbeln and Eilenburg water depths were calculated with Lisflood-FP (Bates and de Roo, 2000) and were provided by Apel et al. (2007).

The results of the loss estimation were compared with each other and with official loss records on municipality level, which were provided by the Saxonian Bank of Reconstruction (SAB, personal communication, 2004). The official loss records of the SAB contain the sum of repair costs for damaged buildings, equipment as well as goods, products and stock, which was paid to private companies to compensate their losses. The losses to companies in the governmental sector are not taken into account in the SAB compensation scheme, what might lead to differences when comparing the estimated losses with the SAB loss records.

As input data for all models spatially distributed asset values in € per m² for the asset types buildings, equipment as well as goods, products and stock are used (Kreibich et al., 2010). The asset values are further distinguished in three classes of business size and four business sectors (Seifert et al., 2010). In order to keep congruency to the loss records of SAB, the gross stock of fixed assets was used, because it better reflects the repair costs than the net stock. With the help of price indices the asset values were adjusted to the year of the flood event, i.e. 2002.

Information about the contamination of the flood water and precautionary measures, which companies had undertaken before the 2002 flood event, was derived from empirical data (Kreibich et al., 2007). This was only considered in those municipalities where information from more than 10 interviews was available, i.e. Dresden, Döbeln, Eilenburg and Grimma. For both, contamination as well as precaution, the average values were calculated and the corresponding scaling factors were assigned (Table 1).

The meso-scale models were applied using GIS (ArcGis 9) on the basis of raster data with a grid size of 25 m. Overlaying the asset values with the flood extent mask, for every flooded grid cell the asset values per square meter were determined for the four sectors and three classes of company size. The average water depth per grid cell was used to assign the loss ratios via the loss functions to the asset values. From the multiplication of the asset values with the grid cell size and the loss ratio the losses per grid cell were obtained. The losses were then summed up for the different asset types for all grid cells of the municipality. For the asset types of “buildings” and “equipment” the loss estimation ended here. For the asset type of “goods, products and stock”, the calculated values were multiplied with a factor of 0.66. This factor reflects what fraction of all companies sustained losses to this asset type, because in comparison to the asset types “buildings” and “equipment” not all companies must necessarily store “goods, products and stock”. The factor was obtained from a frequency analysis of a question in the empirical data (Kreibich et al., 2007) concerning the types of sustained damages. At this point, FLEMOcs+ the second model stage, considering contamination and precaution, can be applied via a multiplication with scaling factors (Kreibich et al., 2010). The used scaling factors are listed in Table 1. Finally, for the comparison with the loss records of SAB, the losses of all asset types were summed up.

To analyse the performance of the models in the different municipalities in more detail, a cluster analysis (Ward-Algorithm with squared Euclidian distance) was performed with the relative deviations of the estimates of the four models from the recorded SAB-losses. To explain the behaviour of the models, the flood situation and the structure of business in the different municipalities were examined. The water depth of each grid cell in the raster data per municipality was classified into five water depth classes. The structure of businesses was examined using geomarketing data (INFAS GEOdaten, 2001), which provided the number of companies per sector and per company size in every municipality.

**Table 1** Scaling factors for the second stage of the FLEMOcs model (FLEMOcs+) for the municipalities of Dresden, Döbeln, Eilenburg and Grimma.

| | scaling factors for loss ratios of | | |
|---|---|---|---|
| | buildings | equipment | goods etc. |
| Dresden and Döbeln<br>Medium contamination, medium precaution | 1.03 | 0.87 | 0.92 |
| Eilenburg and Grimma:<br>Medium contamination, no precaution | 1.28 | 1.03 | 1.08 |

## 3 MODEL VALIDATION ON THE MICRO-SCALE

The leave-one-out cross validation shows, that the estimates of the FLEMOcs model are good. MBEs show no bias, except for a slight underestimation of the loss ratios of goods, products and stock by FLEMOcs+ (Table 2). Mean absolute errors range between 23% and 31%, root mean square errors range between 30% and 37% (Table 2).

Loss ratios were estimated accurately by FLEMOcs for all three loss types with few exceptions (Fig. 1). The building loss ratios were overestimated in the transport, storage and communication sector as well as in the water depth classes below 10 cm, 41-60 cm and 201-250 cm (Fig. 1, top). The equipment loss ratios were underestimated in the electricity, gas and water supply as well as construction sectors and overestimated in the lowest and highest water depth classes (Fig. 1, middle). The goods, products and stock loss ratios were underestimated in the mining and quarrying, electricity, gas and water supply and the hotels and restaurants sectors and overestimated in the trade and repair sector by FLEMOcs+. Additionally, the goods, products and stock loss ratios were overestimated in the lowest water depth class and underestimated in the 301-350 cm class (Fig. 1, bottom).

Overall, the FLEMOcs model has potential for improvements in some sectors which have very few companies in the database and for very low as well as very high water depths. The estimates of the building loss ratios are most accurate in comparison with the estimates of the loss ratios of equipment and goods, products and stock (Table 2, Fig. 1). The second stage of the FLEMOcs model doesn't lead to a reduction of errors but it results in a slightly larger variability within the distribution of errors concerning building and equipment loss ratios (Table 2).

**Table 2** Error statistics for estimated loss ratios of the interviewed companies (MBE: mean bias error, RMSE: root mean squared error, MAE: mean absolute error).

| loss types | models | MBE | MAE | RMSE |
|---|---|---|---|---|
| building | FLEMOcs | 0.00 | 0.23 | 0.30 |
| | FLEMOcs+ | 0.00 | 0.23 | 0.31 |
| equipment | FLEMOcs | 0.00 | 0.30 | 0.36 |
| | FLEMOcs+ | 0.00 | 0.30 | 0.37 |
| goods etc. | FLEMOcs | 0.00 | 0.31 | 0.35 |
| | FLEMOcs+ | -0.01 | 0.30 | 0.35 |

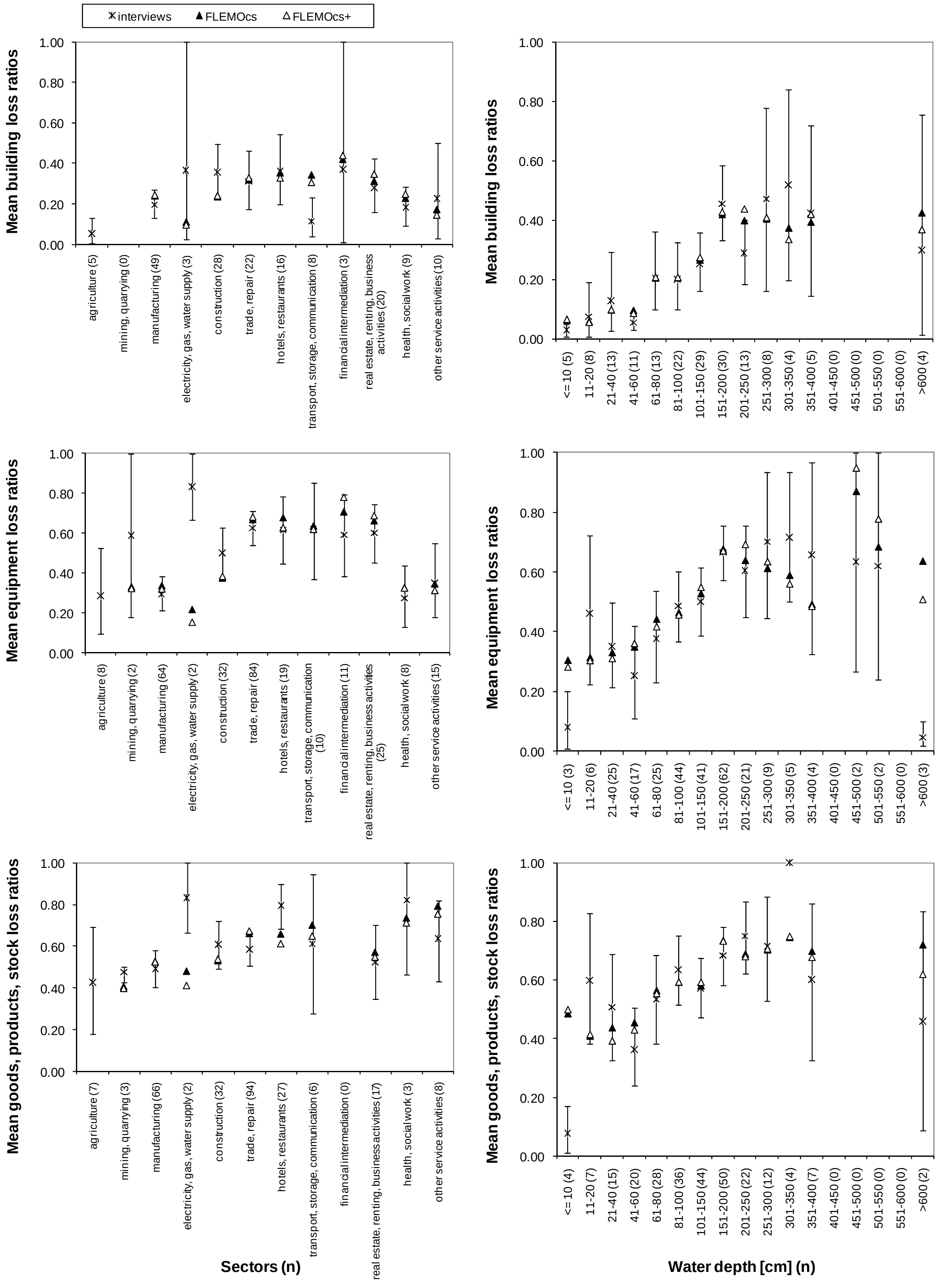



**Fig. 1** Surveyed and estimated mean ratios of losses to buildings (top), equipment (middle) and goods, products and stock (bottom). For the surveyed data the mean and the 2.5% to 97.5% confidence intervals, calculated by bootstrap, are shown (number of samples, *n* are given in brackets following the *x*-axis labels).

# 4 MODEL VALIDATION ON THE MESO-SCALE

## 4.1 Comparison of different meso-scale loss functions

For an evaluation of the model on the meso-scale, FLEMOcs loss functions are compared to other relative, meso-scale loss functions (Table 3). The loss functions are derived from empirical data or with a mixed empirical-synthetic approach. The empirical data base of the Hydrotec (Emschergenossenschaft and Hydrotec, 2004), MURL (2000) and ICPR (2001) models originates from the German flood damage data base HOWAS (for further details see Merz et al., 2004). The listed models differ concerning the types of flood losses, which they are able to estimate. With ICPR (2001) it is possible to estimate separately losses to buildings, losses to mobile inventory (machines, products, stock etc.) and losses to immobile inventory, which equates with losses to equipment. MURL (2000) only allows a distinction of losses to buildings and losses to inventory. Hydrotec (Emschergenossenschaft and Hydrotec, 2004) estimates losses to buildings in combination with losses to equipment, resulting in only one figure. FLEMOcs results in three figures covering losses to buildings, equipments as well as goods, products, and stock.

Concerning parameters, which determine the loss, Thieken et al. (2005) distinguish impact and resistance parameters. Impact parameters reflect the specific characteristics of a flood event at the object under study, e.g. water depth, flow velocity, contamination. Resistance parameters characterise the flood prone objects, e.g. the object type or size, the type and structure of a building, the mitigation measures undertaken. The most important impact parameter, which all of the listed models use, is the water depth (Table 3). FLEMOcs additionally takes contamination into account. Concerning the resistance parameters all models use information on the business sector, following the European Nomenclature of economic activities (NACE - Nomenclature statistique des Activites economiques dans la Communaute Europenne; Eurostat, 2002), in combination with land use data. FLEMOcs additionally takes into account the size of companies in terms of the number of employees and precaution.

**Table 3** Meso-scale loss models for companies using relative loss functions.

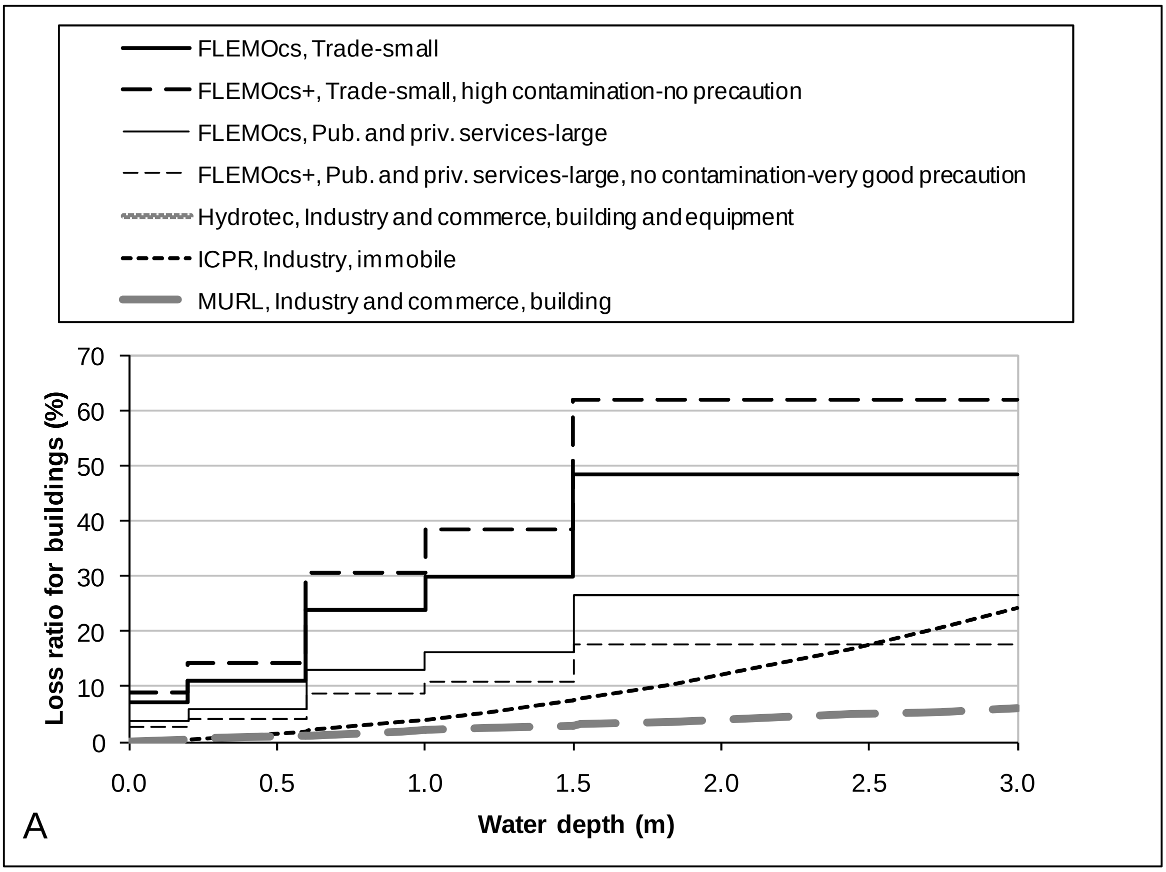
| | Model development | Types of flood loss | Impact parameters | Resistance parameters |
|---|---|---|---|---|
| MURL (Germany) (MURL, 2000) | empirical | two figures covering building and inventory | water depth | business sector |
| ICPR (Germany) (ICPR, 2001) | empirical - synthetic | three figures covering building and mobile and immobile inventory | water depth | business sector |
| Hydrotec (Germany) (Emschergenossenschaft and Hydrotec, 2004) | empirical | one figure including building and inventory | water depth | business sector |
| FLEMOcs (Germany) (Kreibich et al., 2010) | empirical | three figures covering building; equipment; and goods, products, and stock | water depth / contamination | business sector / size of companies (no. of employees) / precaution |

Figure 2 compares the loss ratios for buildings, equipment and inventory plotted against the water depth for the different loss functions. For FLEMOcs the functions for the sectors with the highest and lowest loss ratios are shown, as well as the increase or decrease when the worst or best case concerning contamination and precaution are included. The functions of FLEMOcs differ insofar, as they are step functions, whereas the other functions are continuous. The functions of MURL are linear functions. ICPR uses a quadratic equation for the building loss ratio and linear functions for equipment and inventory. The Hydrotec function is a root function, but there is no distinction drawn between a loss ratio for building and a loss ratio for equipment. Therefore the Hydrotec-function is shown in Fig. 2A and 2B.

For building loss ratios for a water depth up to 50 cm the FLEMOcs loss functions are all within the range which is spanned by the other functions (Fig. 2A). Whereas the lower functions (large companies in the sector of public and private services) always remain in this range, the upper functions (small companies in the sector of trade) from 50 to 150 cm of water depth are repeatedly cutting the function of Hydrotec and at water depths over 150 cm are clearly higher than all other functions. This means that for lower water depths the building loss functions of FLEMOcs are comparable with other loss functions, which are already used in Germany. For higher water depth some loss functions of FLEMOcs show higher loss ratios in comparison with the other models, especially if the second model stage is taken into account with an occurrence of severe contamination and no precautionary measures.

For equipment losses the lower functions of FLEMOcs (large companies in the sector of public and private services) are in the same range as the shown functions of ICPR and Hydrotec (Fig. 2B). For a water depth of more than 200 cm the functions of ICPR and Hydrotec display higher loss ratios than the low FLEMOcs functions. The upper loss functions of FLEMOcs for equipment (small companies in the sector of trade) show loss ratios which are twice as high as the loss ratios shown by ICPR and Hydrotec. This means that comparable estimates derived by the different models are to be expected only for the lower FLEMOcs functions.

Concerning loss ratios of inventory only the lower function of FLEMOcs (large companies in the sector of corporate services) are in the same range as the function of MURL for the inventory of companies in the sectors of trade or services (Fig. 2C). The MURL-function for companies of the producing industry is for the displayed water depth always lower than the FLEMOcs functions. The loss ratios of the upper FLEMOcs loss functions (middle-sized companies in the sector of public and private services) are more than twice as high as the MURL functions. Therefore comparable results are to be expected only from the lower FLEMOcs functions and the MURL-function for companies in the sectors of trade or services.



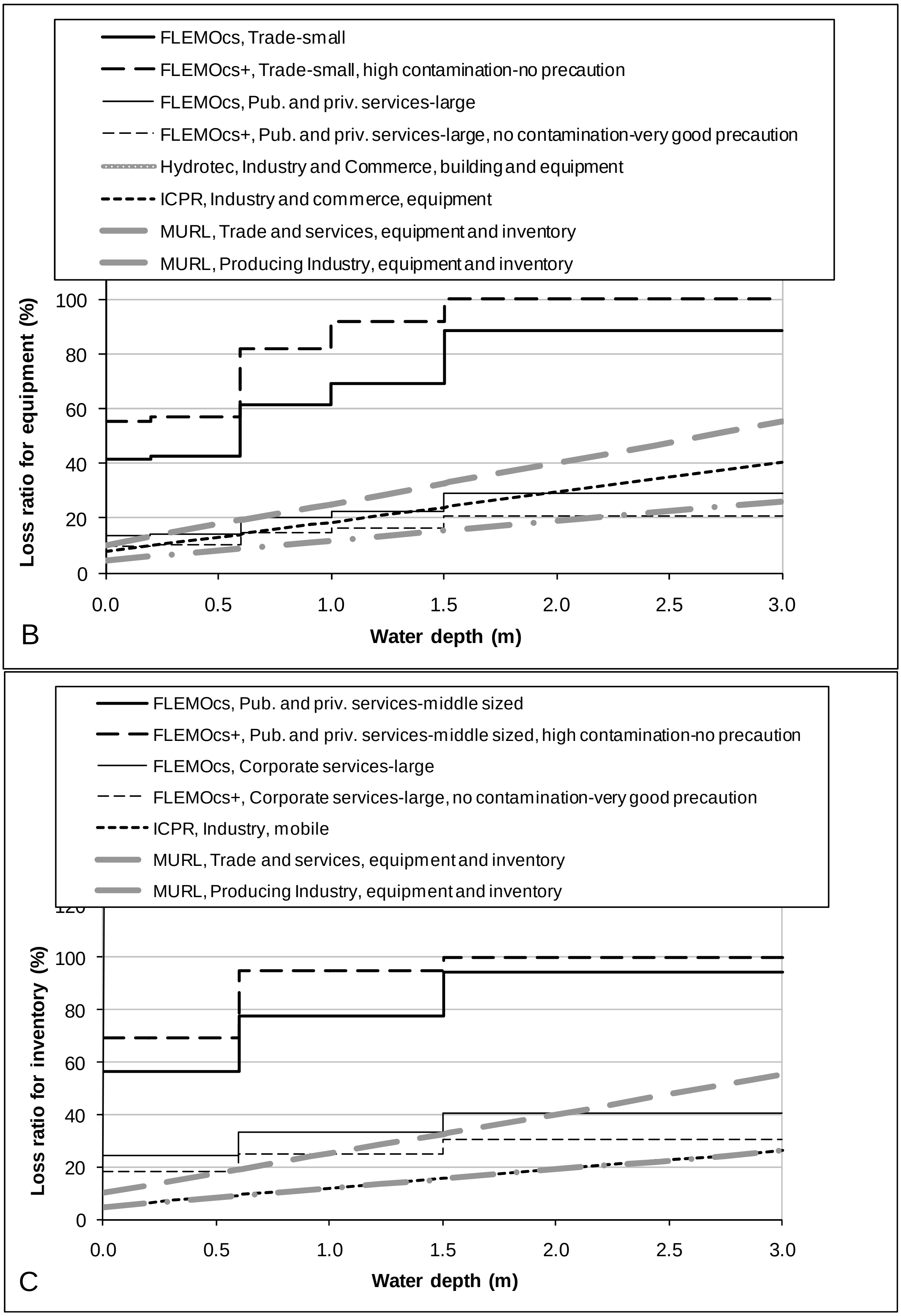



**Fig. 2** Comparison of meso-scale loss functions for buildings (A), equipment (B) and inventory (C).

## 4.2. Application of FLEMOcs in municipalities affected by the August 2002 flood

The results of the application and validation of different meso-scale models are shown in Fig. 3. The estimated losses for all models are plotted against SAB loss records. The black line marks the equality between the SAB loss records on the x-axis and the estimated losses on the y-axis. Both axes have a logarithmic scale. The results of FLEMOcs+ in Dresden, Döbeln, Eilenburg and Grimma where contamination and precaution could be considered are shown in Table 5.

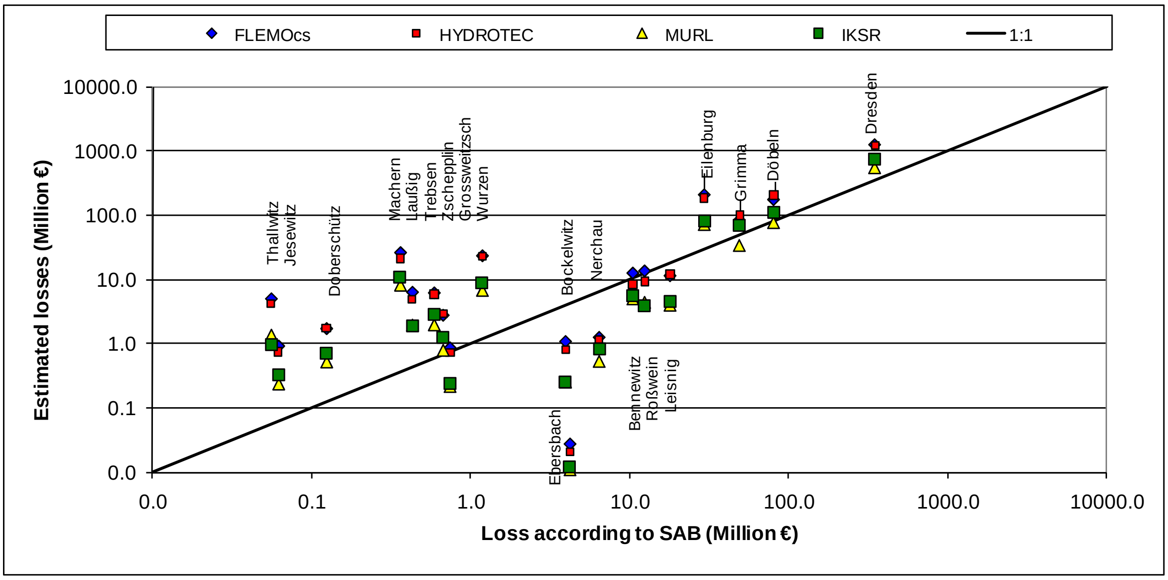



**Fig. 3** Comparison of the results of model application with SAB loss records. The four models mentioned in the legend were applied to the 19 municipalities, whose names are given in the diagram. Underlines and script indicate the assignment to the different clusters: double underline = cluster 1, italic script = cluster 2, single underline = cluster 3, normal script = cluster 4.

As expected from the comparison of loss functions (Fig. 2), the estimated losses of the models of MURL and ICPR are always lower than the estimated losses of Hydrotec and FLEMOcs. The results for Hydrotec and FLEMOcs are very similar, even though Hydrotec does not take into account losses to inventory. However, differences between the model results are small in comparison to the difference to the SAB data, showing the high impact of the disaggregated asset database used for all model applications. Apparently, more accurate land use data should be used for asset disaggregation as already shown by Wünsch et al. (2009).

The cluster analysis of model behaviour (i.e. relative deviations of the estimates from the recorded SAB-losses) grouped the municipalities into 4 clusters (Table 4). Clusters 1 and 3 contain only one municipality each (Thallwitz and Machern, respectively). They are both characterised by extreme overestimations (> 1000%) of the losses by all four models. They are characterised by a very small fraction of affected companies (low SAB loss records, small number of applications) in comparison to the total number of companies in the municipality. The extreme overestimations of all models are due to high uncertainties of the disaggregated asset values. For the meso-scale model application all company asset values of a municipality are disaggregated on land use areas. To every land use area average asset values per square meter are assigned. In reality even within one land use area the asset values are not equally distributed. If a very small fraction of the total number of companies in the municipality is affected, overestimations can't be avoided. Cluster 2 is also characterised by loss overestimations by all four models, however, the overestimations of the models MULR and ICPR are relatively moderate. This cluster shows numbers of requests to SAB and numbers of companies slightly below median and low SAB loss records. Clusters 1 to 3 show relatively large areas of high water depth over 1 m (cluster 1) and 1.5 m (cluster 2 and 3). Also here, more accurate disaggregated asset values would be necessary. Additionally, it has been shown before, that the uncertainty in flood loss modelling depends on the number of flooded objects. Statistically derived damage estimates for few or even single objects are extremely problematic (Merz et al., 2004). For the commercial sector with its high variability specific local information may be essential, particularly in small municipalities. Additionally, the overestimation of all models might be due to the fact, that SAB loss records do not consider losses to companies owned by public administration, whereas in the model estimates these losses are also included. Cluster 4 is characterised by relatively good estimates by FLEMOcs and Hydrotec, while MURL and ICPR underestimate the losses. The municipalities in cluster 4 are characterised by very high SAB loss records, many applications to SAB indicating many affected companies and generally many companies per municipality. Apparently, this cluster contains the larger municipalities of the sample. Additionally, the municipalities in cluster 4 show comparatively large areas of shallow water depths below 1.5 m. The clusters show no apparent differences between the distribution of business sectors and company sizes, which suggests no direct linkage between business structure and the results of loss estimation. These findings indicate that the meso-scale use of FLEMOcs is advantageous in large areas where many companies are affected, which is actually its purpose.

**Table 4** Median values of loss data, business structure and water depth in four clusters and all municipalities

| Cluster | SAB loss record (M€) | No. of applications+ to SAB per municipality | Relative deviation of the estimates from the recorded SAB-losses | | | | No. of companies per municipality | Size of companies (% per municipality) | | | Sector of companies[#] (% per municipality) | | | | Water depth classes (% of grid cells per municipality) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | FLEMOcs (%) | Hydrotec (%) | MURL (%) | ICPR (%) | | Large | Middle | Small | PI | T | CS | PPS | < 0.2m | 0.2-0.6 m | 0.6-1m | 1-1.5m | > 1.5m |
| 1* | 0.06 | 9 | 8851 | 7441 | 2382 | 1663 | 173 | 1 | 16 | 83 | 27 | 29 | 20 | 23 | 0.6 | 1.9 | 4.5 | 18.2 | 74.9 |
| 2 | 0.43 | 25 | 1369 | 1103 | 325 | 432 | 184 | 1 | 23 | 77 | 24 | 37 | 13 | 24 | 0.8 | 1.8 | 3.3 | 7.0 | 88.7 |
| 3* | 0.36 | 16 | 7110 | 5803 | 2182 | 2829 | 370 | 1 | 31 | 68 | 23 | 37 | 20 | 20 | 0.2 | 0.4 | 1.5 | 4.1 | 93.9 |
| 4 | 11.40 | 120 | 18 | -12 | -58 | -58 | 281 | 0 | 20 | 80 | 24 | 34 | 17 | 24 | 1.6 | 3.8 | 5.0 | 8.2 | 81.7 |
| all | 3.90 | 27 | 258 | 242 | 19 | 84 | 198 | 1 | 21 | 79 | 24 | 36 | 17 | 23 | 1.1 | 2.1 | 4.4 | 7.7 | 85.0 |

+ The number of applications to the SAB is an indicator for the number of affected companies: average number of applications per company was 2, maximum 23, in Saxony.

* Clusters 1 and 3 contain one municipality only.

# PI: producing industry, T: trade, CS: corporate services, PPS: private and public services.

The application of FLEMOcs+ shows, that the consideration of contamination and precaution leads only in Döbeln to a slightly improved estimate compared with the SAB loss record (Table 5). Thus, this small sample of meso-scale applications of FLEMOcs+ indicates, that this second model stage is not able to improve the loss estimates, which is in accordance with the results on the micro-scale.

**Table 5** Comparison of the results of FLEMOcs and FLEMOcs+ (consideration of contamination and precaution) with SAB-loss-records.

| Municipality | SAB (M€) | FLEMOcs (M€) | FLEMOcs+ (M€) |
|---|---|---|---|
| Eilenburg | 29.4 | 207.3 | 237.7 |
| Grimma | 48.9 | 83.8 | 98.5 |
| Döbeln | 80.4 | 173.8 | 166.3 |
| Dresden | 347.8 | 1246.1 | 1302.5 |

## 5 CONCLUSIONS

The micro-scale leave-one-out cross validation of the newly developed FLEMOcs model 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 and high water depths.

The model application on the meso-scale and comparison with official loss records as well as with other models shows that in municipalities with minor losses, i.e. SAB loss record below 1.2 million Euros, all models overestimate the losses. FLEMOcs provides good results in large areas with many affected companies and high expected losses, which is its purpose. Model improvements for high water levels seem necessary. The second model stage FLEMOcs+ is not able to improve the loss estimates and is therefore not recommended. Particularly in small areas loss estimation for the commercial sector is associated with high uncertainties. For larger or very special companies it seems necessary to derive damage estimates through personal interviews with plant managers, property owners etc. Particular effort should be put in the development of accurate exposure data, i.e. disaggregated asset values.

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