# GIS-based Estimation of Flood Damage to Arable Crops

## *GIS-basierte Abschätzung von Hochwasserschäden landwirtschaftlicher Nutzpflanzen*

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**Abstract:** Floods are a serious risk, particularly in view of their climate change-induced increasing intensity and frequency. Hence, a further growth of flood consequences is to be expected. The reason is either, higher flood damage caused by the higher exposure or the rising effort to avoid and to mitigate the negative consequences. Damage and risk analysis often focus on the built environment because of its value dimension and its resulting high potential flood losses. In this context, damage to arable crops are rarely included and almost solely by rough estimates. The reason is the difficulties to assess appropriate values especially the seasonal and annual changes. To fill the gap, the paper presents a new approach for a detailed analysis of damage to arable crops considering the vulnerability of different crop types and the seasonal crop growth. It results in a wide range of applications including the use for the evaluation of compensation payments. In cooperation with the responsible authorities, this may be of particular interest for dike relocations and the flooding of flood polders.

**Keywords:** GIS, agriculture, flood vulnerability, risk assessment, damage functions

***Zusammenfassung:*** *Hochwasser stellt eine ernstzunehmende Gefahr dar, da durch Klimawandel mit einer Zunahme von Häufigkeit und Intensität zu rechnen ist. In der Folge werden auch die Konsequenzen weiter zunehmen, die entweder durch höhere Schäden oder durch einen höheren Aufwand zur Vermeidung bzw. zur Verminderung negativer Folgen entstehen. Im Hinblick auf ökonomische Schäden steht bei einer Vielzahl von Untersuchungen die wertintensive, gebaute Umwelt im Vordergrund der Betrachtung. Angesichts dessen, wurden die Schäden an landwirtschaftlichen Nutzpflanzen selten betrachtet oder nur mittels überschlägiger Werte in die Risikobetrachtungen einbezogen. Der vorliegende Beitrag zeigt einen neuen Ansatz auf, mit dem sich landwirtschaftliche Schäden im Überflutungsfall detailliert ermitteln lassen. Dieser Ansatz berücksichtigt insbesondere die Verletzbarkeit für konkrete Fruchtarten und die jahreszeitliche Entwicklung der Pflanzen. Insgesamt ist damit ein interessantes Tool entstanden, welches – in Zusammenarbeit mit den zuständigen Behörden – auch bei der Bewertung von Ausgleichsleistungen eingesetzt werden kann, was insbesondere bei Deichrückverlegungen und bei Flutpoldern von Interesse ist.*

***Schlüsselwörter:*** *GIS, Landwirtschaft, Hochwasservulnerabilität, Risikobewertung, Schadensfunktionen*

# 1 Introduction

Floods are one of the major threats to areas inhabited or cultivated by humans worldwide. In the light of climate change and the expected increase of flood frequency and flood intensity (Hennegriff et al., 2006), an increase of negative consequences for all receptors exposed to flood risks is to be expected. For this reasons, it needs a clear understanding of damage process and the effects of mitigation measures. This is in line with research activities in recent

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decades. It includes especially the development of methods and tools, which determine potential flood damage and the effects of flood mitigation measures. However, the focus has mostly been on settlement areas with the highest potential of economic losses (Förster et al., 2008). Numerous studies are therefore dedicated to the development of depth-dependent damage functions for the built environment and their application in flood-prone settlement areas (cf. Merz et al., 2010; Neubert et al., 2016, Schinke et al., 2012). In contrast, damage assessment for agricultural land is often based on lump sum values or simple estimates (Förster et al., 2008). The reasons are the lower economic losses on agricultural land in the event of flooding (cf. Brémond et al., 2013; Förster et al., 2008; Klaus et al., 2016) and the insufficient data basis regarding the vulnerability of agricultural crops (Dutta et al., 2003). The diversity of species and varieties of cultivated crops, the varying vulnerability to flood events and the seasonal variations in damage values are obstacles to this.

Some studies on agricultural flood damage take into account the variation in the vulnerability of arable land during the course of the year (Förster et al., 2008; Klaus et al., 2016; Win et al., 2018). Studies addressing the formulation of depth-damage functions for individual crop types are rarely found (Citeau et al., 2003; Ganji et al., 2012) and mostly concern typical Asian crops like rice and beans (Dutta et al., 2003; Nguyen, 2017). These damage functions can be transferred to crops cultivated in Central Europe to a limited extent only.

In a previous study, a method was therefore developed for calculating the economic flood damage of agricultural land in Central Europe as a function of water depth (Höhnel, 2016). The basis was a statistics-based distribution of crops on arable and grassland areas in the case study. In addition, crop-specific water depth damage-functions based on damage compensation amounts of the flood aid of the federal states Saxony and Saxony-Anhalt for the Elbe flood 2013 were derived. Monthly damage values have been determined according to average plant growth heights.

In this study, more detailed statistical crop shares data are used. In addition, updated damage compensation amounts for Saxony allow recalculating and comparing the results for the same study area. Further methodological enhancements are intended to serve simplification. For example, a combined damage function based on crop shares and the use of generalised water depth data are applied. The resulting potential damage amounts are analysed and discussed.

# 2 Data and Method

## 2.1 Study Area

The study area is an agricultural area along the Elbe river floodplain in northern Saxony (Germany), east of the town Riesa (Figure 1). At this location, the Elbe floodplain widens after passing the transition from the low mountain range and hilly region (Saxon Loess Fields) in the south to the lowlands of Northern Saxony (part of Northern Lowland of Germany). Administratively, the study site is part of the district Meißen. Its location is about 40 km northwest of the federal state capital Dresden. The extent of the study area is 9 by 6 km, whereof 15 km² (27.8 %) is located in designated flood areas according to a recurrence interval of 100 years. 10.8 km² (20 %) of the area is flood-prone agricultural land.

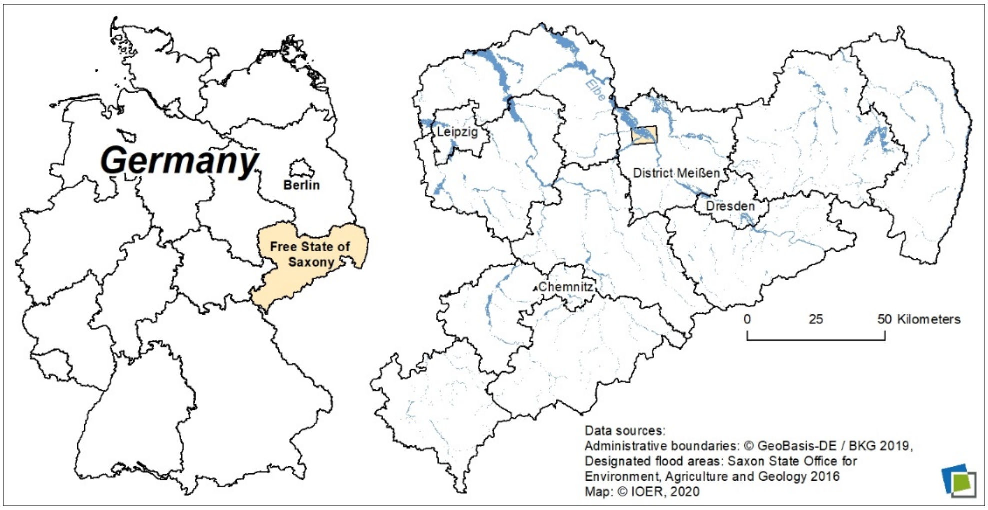


**Fig. 1:** Location of the study area Elbe floodplain close to Riesa – left: Saxony within Germany; right: study area within Saxony including designated flood areas (blue)

## 2.2 Data and Pre-processing

An overview of the data processing and modelling approach is shown in Figure 2. The description of all steps is to be found in the subsequent sections.

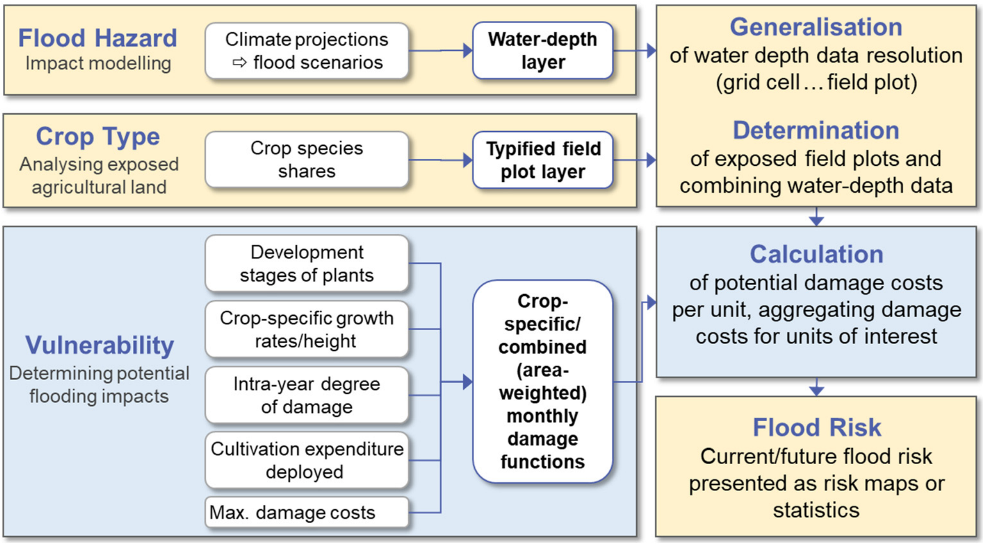


**Fig. 2:** Data processing and modelling approach for analysing potential flood damage to arable crops; GIS processing steps (light orange boxes), spreadsheet/database calculations (light blue boxes)

### 2.2.1 Water Depth

The water depth data used in this study (Figure 3) originate from the previous project VERIS-Elbe where numerous future flood scenarios for the German Elbe catchment have been modelled. These scenarios incorporate, among others, regional climate change projections as well as options for action. For the current analyses, we have chosen a reference flood with a 100-year recurrence interval. The basis for calculating the flood scenarios was a digital terrain model (DTM) with a raster resolution of 2 m and a height accuracy 0.1 m (Neubert, 2015). A cascading model procedure was applied for calculation including the flood simulation model LISFLOOD, the hydrodynamic model WAVOS, the flow model Hydro_AS-2D, and the model SMS for modelling the water depth (Schanze et al., 2015). The water depth values by centimetre have been simplified into decimetres [dm] by rounding. In addition, the raster data set was converted into polygons, which thus form partial units of the parcels. Its level of detail can be lowered to reduce the number of single polygons at the same time by generalising the height resolution to e. g. 0.5 m or 1 m.

### 2.2.2 Field Plot Location

For the spatial location of field plots, we used data of the annually updated InVeKoS[1] (Siemer & Nowak, 2014). This dataset is available for download online (SMUL, 2018). Alternatively, it is possible to use the biotope map BTLNK[2], but the current data set for Saxony is from 2005 already. If less detailed data is sufficient, data of ATKIS[3] can be used.

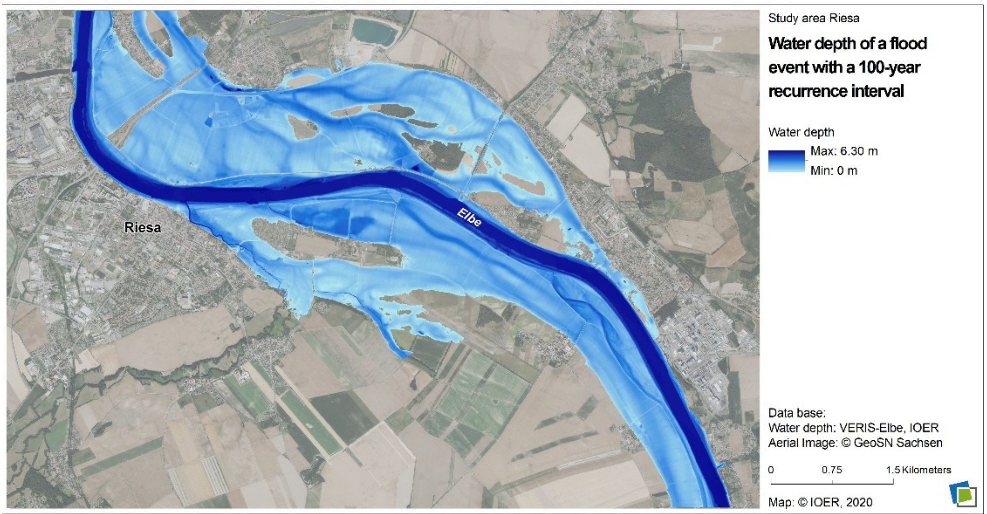


**Fig. 3:** Extent of flooded area and water depth of a flood event with a 100-year recurrence interval

1 *Integriertes Verwaltungs- und Kontrollsystem*/Integrated Administration and Control System
2 *Biotoptypen- und Landnutzungskartierung*/Biotope Type and Land Use Map
3 *Amtliches Topographisch-Kartographisches Informationssystem*/Authoritative topographic cartographic information system

InVeKoS (but also BTLNK and ATKIS) allow separating arable land and grassland. Within the study area 846.6 ha arable land and 230.4 ha grassland based on InVeKoS.

### 2.2.3 Crop Selection and Spatial Distribution

To estimate potential flood damage on agricultural land as accurately as possible, knowledge of the crop species cultivated on the individual field plots is necessary. These data are part of the InVeKoS data set, but they are not available for the public due to data protection regulations. Since the exact spatial location was not available, the statistical share of the crop species cultivated was used instead. In previous tests, the identification of crop species shares was based on a statistical report on land use and harvest of the Statistical State Office of the Free State of Saxony for the district Meißen (Höhnel, 2016). For this study, we received detailed annual statistics based on InVeKoS for the designated flood areas (100-year recurrence interval) of the district Meißen from 2010 until 2017 (LfULG, 2019b). The data set was reclassified according to the damage functions available for specific crop types. For the further calculations, the mean values of the crop shares of the years 2010-2017 were used (Table 1). The InVeKoS crop types 'other areas (including permanent crops)' (7.87 %), 'other root crops' (0.01 %), 'other oleaginous fruits' (1.32 %), 'other cereals' (0.37 %) as well as 'horticulture' (1.16 %) could not be considered due to missing damage functions. The location of crops was distributed manually on a random basis without consideration of crop-specific site requirements by attributing the InVeKoS field plots according to the crop type's shares as shown in Figure 4.

### 2.2.4 Flood Damage Compensation Amounts and Damage Functions

After the Elbe flood in June 2013, compensation amounts were paid to farmers in Saxony and Saxony-Anhalt as flood aid. These crop-specific compensation amounts for the total loss were the basis for the flood damage calculations in Höhnel (2016). For this study, current damage amounts (as of January 2019) for Saxony were used (LfULG, 2019a; see Table 1).

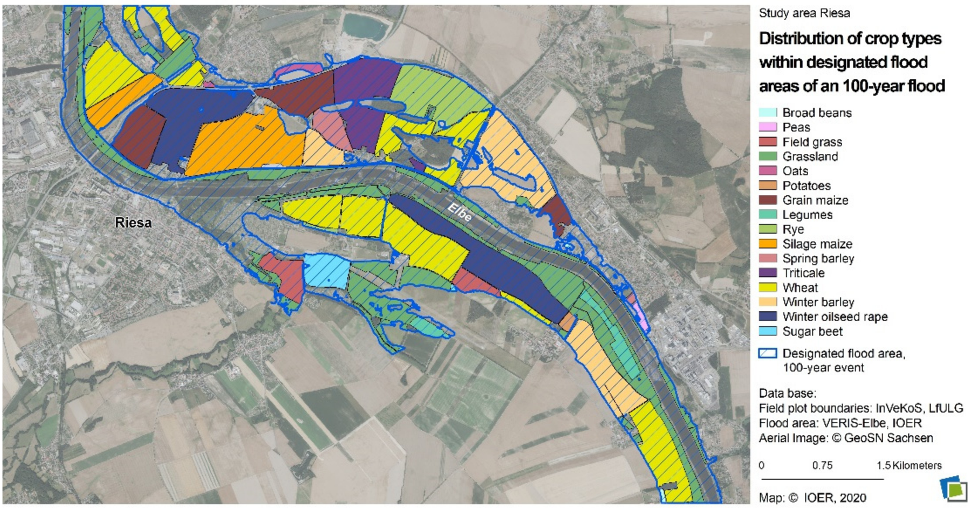


**Fig. 4:** Location of crop types in the designated flood area (100-year recurrence interval)

These were determined based on planning and evaluation database for Saxony's agriculture, which can be accessed online (LfULG, 2020) and are used, among others, for the calculation of compensation payments, indemnities and allowances. A 5-year average of agricultural market performance in Saxony is used as a basis. Saved costs or consequential costs resulting from the time when the flood occurred in the course of the year were not taken into account (LfULG, 2019a). For most crop types, there are additional damage amounts for organic farming available, which are usually significantly higher than for conventional farming. They were not taken into account, however, as there is no location of organically farmed areas available (6 % share according to LfULG, 2019b).

Subsequently, water depth damage functions for a one-to-three-day flooding were derived for the individual crop types based on the following principles:

- Compensation amounts for 16 crop types according to LfULG (2019a),
- Growth rates of crop types during the year (Gutjahr, 2009; AHDB, 2018a; AHDB, 2018b; DPI, 2011; Pioneer, 2016),
- Vulnerability of crop types to flooding as a function of water depth depending on the development stage of the plant (LfL, 2005),
- Variation of the amount of damage in the course of the year depending on the work already carried out and the related costs (LfL, 2005; Erftverband, 2009; Dutta et al., 2003).

**Table 1:** Share of crop types in the designated flood area (100-year recurrence interval) in the district Meißen and shares of the assigned crop types in the study area (*Grassland* is considered separately and is not included in the share of agricultural land)

| **Crop Type** | **Average share of agricultural land (target)** | **Share in this study/field plots classified (actual)** | **Difference actual-target (rounded)** | **Damage compensation amount [EUR/ha]** (LfULG, 2019a) |
|---|---|---|---|---|
| Broad beans | 0.12 | 0.14 | 0.02 | 700 |
| Peas | 0.38 | 0.37 | -0.01 | 683 |
| Field Grass | 3.15 | 3.19 | 0.04 | 1.475 |
| Oats | 0.77 | 0.74 | -0.03 | 770 |
| Potatoes | 0.34 | 0.32 | -0.02 | 6.160 |
| Grain maize | 8.05 | 8.09 | 0.04 | 1.440 |
| Legumes | 2.31 | 2.39 | 0.08 | 1.445 |
| Rye | 6.45 | 6.44 | -0.01 | 765 |
| Silage maize | 11.55 | 11.61 | 0.05 | 1.306 |
| Spring Barley | 1.85 | 1.82 | -0.03 | 798 |
| Triticale | 6.69 | 6.65 | -0.04 | 840 |
| Wheat | 26.67 | 26.67 | 0.00 | 1.222 |
| Winter Barley | 13.78 | 13.74 | -0.04 | 1.015 |
| Winter oilseed rape | 15.49 | 15.44 | -0.05 | 1.349 |
| Sugar Beet | 2.40 | 2.40 | 0.00 | 2.117 |
| *Grassland* | *30.84* | *30.84* | *0.00* | *1.175* |

The following additional assumptions were made (cf. Höhnel 2016):

- Compensation amounts represent the maximum total loss occurring during the year.
- The maximum losses are decreased, provided that the crop is not yet about to be harvested at the time of flooding, thus saving labour and costs for e. g. harvesting. According to LfL (2005), this results in monthly percentage damage amounts. Costs for clearing and preparing the arable land or a possible new sowing are not taken into account.
- If the water depth is lower than the growth height of the crop at the time of flooding, a linear reduction of the damage is assumed for simplicity. The full monthly percentage damage amount therefore only applies if the plant is completely flooded.
- Grassland, field grass and legumes are treated differently. For these crops with multiple harvests per year, a total loss is assumed even at a water depth of 1 dm. However, the amounts of damage vary over the year, as the respective harvests vary in yield.
- Damage resulting from impacts like flow velocity, contamination or accumulation/ erosion are excluded in this study.

Figure 5 shows the depth-damage functions for the 16 crops considered exemplified for the month of June. To further simplify the calculation and since no exact spatial distribution of the crops is available, a combined damage function was determined, which is composed according to the area shares of all crop types including grassland (see Table 1).

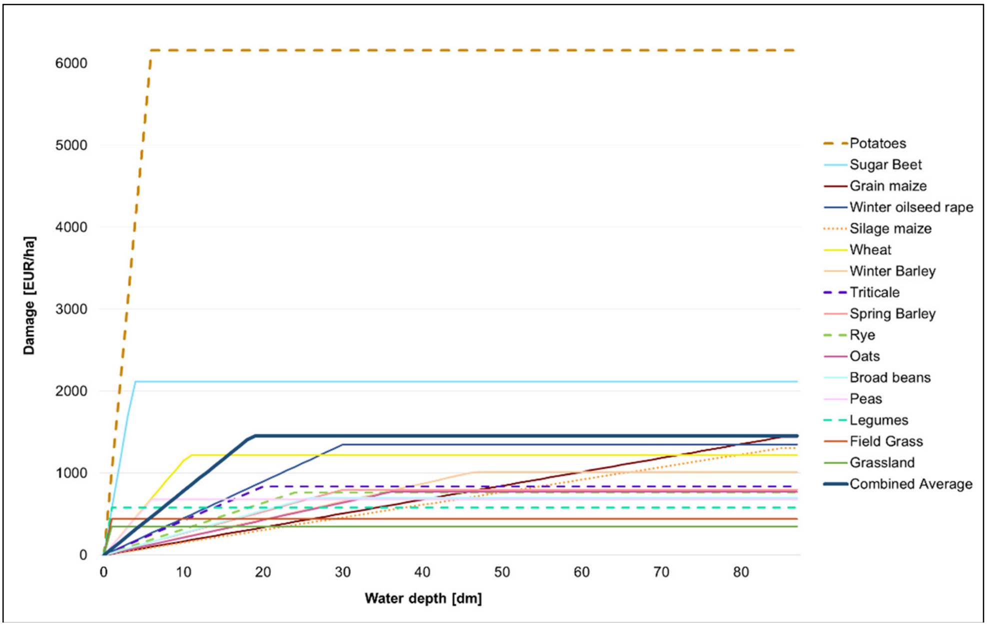


**Fig. 5:** Depth-damage functions for the 16 crop types considered and combined average weighted by crop area exemplified for the month of June

### 2.3 Flood Damage Calculation

The damage calculation itself is a spatial combination of the aforementioned data sets and is based on the previous flood damage model HOWAD (Neubert et al., 2016). It can be implemented by GIS procedures, by database queries or by spreadsheet calculations. For this study, an Excel spreadsheet was created that allows calculating the flood damage to agricultural land. The only required input is an attribute table, e. g. exported from ArcGIS, of a shape file containing the arable and grassland areas including following information: Area [ha], crop type and water depth [dm]. This can be obtained from a combination of the crop type data with the water depth data (polygons). The damage functions of the individual crop types are provided as spreadsheet. From the corresponding spreadsheets, the monthly damage values in percent and the corresponding damage amounts in EUR/ha are calculated according to the water depth using formulas. The result can be easily combined with the original data set after calculation. The size of the investigation area as well as the level of detail of the water depth data (number of single polygons) influences the calculation time, but is only limited by the software-specific row limit when using Excel.

## 3 Results and Discussion

The calculated total damage for the study area considering a 100-year flood event and the results are summarised in Figure 6. The damage sums are available separately for the respective months. For better comparability, however, they are shown as a line chart that connects the damage sums of the individual months representing a damage curve in the course of the year. At the same time, it is easily possible to re-import the result into GIS by re-joining the calculation spreadsheet to the original attribute table. This way, the result can be displayed as a map as exemplified in Figure 7.

Based on the damage values of LfULG (2019a), a potential maximum total damage of about EUR 1.3 million in case of a 100-year flood was calculated for the study area. This calculation does not consider growth periods of the plants and assumes a maximum flooding. Compared to the use of damage functions, this leads to an overestimation of the damage (cf. Förster et al., 2008).

The comparison of combined and crop-specific damage functions also revealed different total loss amounts. The combined damage function leads to a significantly higher total damage than the use of the crop-specific damage functions. For the month of June, the total damage sum of EUR 880,000 for the combined damage function is 39 % higher than the total damage sum of EUR 633,000 for the use of the crop-specific damage function. For the month of September, the difference between the calculation results for the total damage is even more pronounced at a plus of 156 %.The considerably higher damage values when using the combined damage functions are caused by the inclusion of the damage functions for grassland, field grass and legumes. These three crops with a large share are damaged to a maximum extent already at a water depth of 1 dm and thus lead to an overestimation of the damage. In this form, the combination has not proven to be meaningful and it indicates a need of further refinement. A division of the combined damage function into at least two sub-functions seems to be a reasonable solution. In principle, however, the use of combined damage functions can be considered useful, as the calculation effort can be reduced (especially when analysing large areas) and the exact spatial distribution of the cultivated areas (which changes annually anyway) becomes irrelevant.

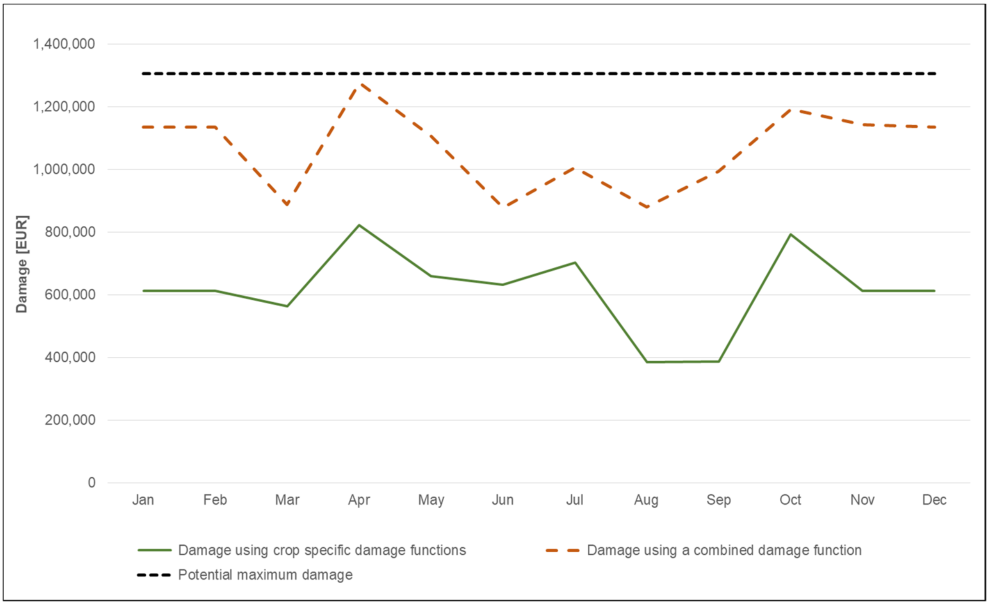


**Fig. 6:** Overview of total losses for all calculated options during the year

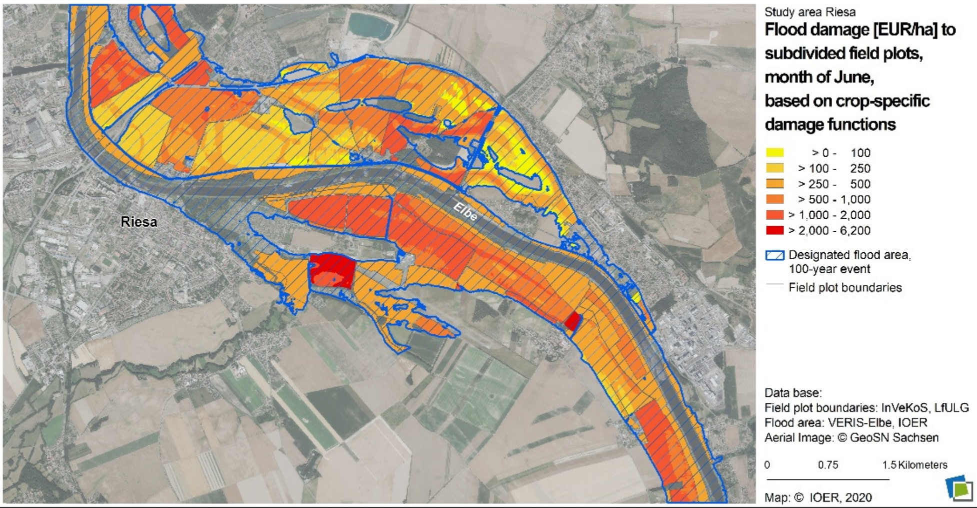


**Fig. 7:** Example of a flood damage map for the month of June using crop-specific damage functions (overall damage 634 kEUR); underlying field plots have been generalised using a reduced height resolution of 0.5 m (14,500 polygons)

In the course of the year, the calculated total losses show clear fluctuations. Using crop-specific loss functions, the calculated loss is lowest in August at EUR 386,000 and September at EUR 388,000. The highest losses occur in April with EUR 824,000 and in October with EUR 794,000. Calculations based on the combined damage function also show a similar monthly fluctuation of the loss amounts. The reasons for this can be found in the damage functions: After the main harvest period (August, September) the damage is minor; after the sowing periods (April, October) the young plants are particularly vulnerable.

# 4 Conclusions and Outlook

The results show that a detailed calculation of flood damage to agricultural land is possible. However, there is still potential to improve the results:

- Use of specific up-to-date data indicating the distribution of crop types (possibly recorded by mapping, as not available due to data protection regulations from InVeKoS), possibly also the organically farmed areas;
- Use of up-to-date, regionally determined damage values (alternatively simplified: market prices, cf. Förster et al., 2008, Klaus et al., 2016, Nguyen et al., 2017) since regional climate or soil conditions influence the yield;
- Optimisation of the combined damage function used (see section 3);
- Reduction of the computational effort by generalising the water depths (first tests with reduced height resolution yielded only slightly different results; also the mere use of an average water depth for each arable parcel may be considered, as it can be assumed that farmers make decisions regarding the harvest of a crop for the whole parcel).

The developed method allows the transfer of the procedure to another study area with little effort if data availability is similar. In principle, a rough estimate of the potential total damage for each agricultural used flood area in Saxony can be made without changing the damage functions. For this purpose, only spatial data on the delimitation of the agricultural field plots as well as on the water depth are necessary. For other regions, an adjustment of the damage values and functions is necessary, but is easily possible due to the spreadsheet format chosen. For transferability, it is recommended to use regional data considering specific yields and prices. Several German federal states are offering similar information. For other countries this information need to be gathered from respective sources.

The application enables the estimation of flood damage in the case of a specific event, e. g. in order to be able to predict compensation payments. This procedure is also possible for the use of flood polders. In addition, potential damage can be determined for dike relocations. The current experimental calculations will be further developed and improved. A possible future development would be the implementation of the method in a spatial decision support system (SDSS).

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