Sequential Disaster Forensics: An Application to Floods in the City of Grimma

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Sequential Disaster Forensics: An Application to Floods in the City of Grimma

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ABSTRACT

Disaster risk and losses have been steadily rising in the past decades, highlighting the need to learn from past events. Only a better understanding of the fundamental causes of natural disasters and its impacts on societies can lead to an effective prevention and reduction of disaster risk. In this context, disaster forensics focuses on the analysis and interaction of risk factors (i.e. hazard, exposure, vulnerability and coping capacity) and the identification of underlying risk drivers, in order to tackle them through dedicated action. Results from forensic analysis are twofold: On the one hand, context-specific knowledge to decide on appropriate and evidence-based Disaster Risk Reduction (DRR) measures to mitigate current risk and prevent future one. On the other hand, more generalizable knowledge and evidence on how disaster risk is generated and on the effectiveness of applied DRR measures. In this work, we explore results of disaster forensics through a case study of subsequent floods in 2002 and 2013 in the city of Grimma, Saxony, in Germany. Risk factors are investigated to identify their contribution in increasing or reducing disaster damage, in conjunction with socio-economic impacts on age structure and migration in the mostly affected inner city of Grimma. In particular, we analyse: (i) How much the sequential application of disaster forensics contributes to a better understanding of risk and the identification of the causes of disasters impacts; and (ii) what data are required for performing a disaster forensic analysis.

Key words: Disaster forensics, Natural disasters, risk factors, disaster risk reduction, flood damage, damage data, migration, age structure, city of Grimma, Saxony, Germany.

ZUSAMMENFASSUNG

Katastrophenrisiken und -schäden sind in den letzten Jahrzehnten stetig gestiegen und unterstreichen die Notwendigkeit, aus vergangenen Ereignissen zu lernen. Nur ein besseres Verständnis der grundlegenden Ursachen von Naturkatastrophen und ihrer Auswirkungen auf die Gesellschaft kann zu einer wirksamen Prävention und Reduzierung des Katastrophenrisikos führen. In diesem Zusammenhang konzentriert sich die Katastrophenforensik auf die Analyse und das Zusammenspiel von Risikofaktoren (d.h. Gefährdung, Exposition, Verletzlichkeit und Bewältigungskapazität) sowie die Identifizierung der zugrunde liegenden Risikotreiber, um diesen durch gezielte Maßnahmen zu begegnen. Die Ergebnisse der forensischen Analyse sind vielseitig: Auf der einen Seite kontextspezifisches Wissen, um evidenzbasiert über geeignete Maßnahmen zur Katastrophenrisikominderung (Disaster Risk Reduction, DRR) zu entscheiden, um das aktuelle Risiko zu mindern und zukünftiges einzudämmen. Andererseits verallgemeinerbares Wissen und Erkenntnisse darüber, wie Katastrophenrisiken entstehen und wie effektiv angewandte Risikoreduktionsmaßnahmen sind. In dieser Arbeit untersuchen mithilfe der Katastrophenforensik eine Fallstudie zweier sukzessiver Überschwemmungsereignisse in den Jahren 2002 und 2013 in der Stadt Grimma in Sachsen. Verschiedene Risikofaktoren werden untersucht, um ihren Beitrag zur Erhöhung oder Verringerung von Katastrophenschäden zu identifizieren. Dies geschieht unter Berücksichtigung der sozioökonomischen Auswirkungen auf die Altersstruktur und Migration in der am stärksten vom Hochwasser betroffenen Innenstadt von Grimma. Insbesondere analysieren wir: (i) Inwieweit die sequentielle Anwendung der Katastrophenforensik zu einem besseren Verständnis des Risikos und der Ursachen der Auswirkungen von Katastrophen beiträgt und (ii) welche Daten für die Durchführung einer forensischen Katastrophenanalyse benötigt werden.

Schlagworte: Katastrophenforensik, Naturkatastrophen, Risikofaktoren, Hochwasser, Schäden, Schadensdaten, Migration, Altersstruktur, Grimma, Sachsen.

INTRODUCTION

The town of Grimma is located in the Free State of Saxony, Germany, on the western bank of the Mulde River ("Vereinigte Mulde" in German), 30 kilometres south of Leipzig. The Mulde River is a left tributary of the Elbe River, formed by the confluence of the rivers Zwickauer Mulde and Freiberger Mulde, with origins in the Ore Mountains (Figure 1).

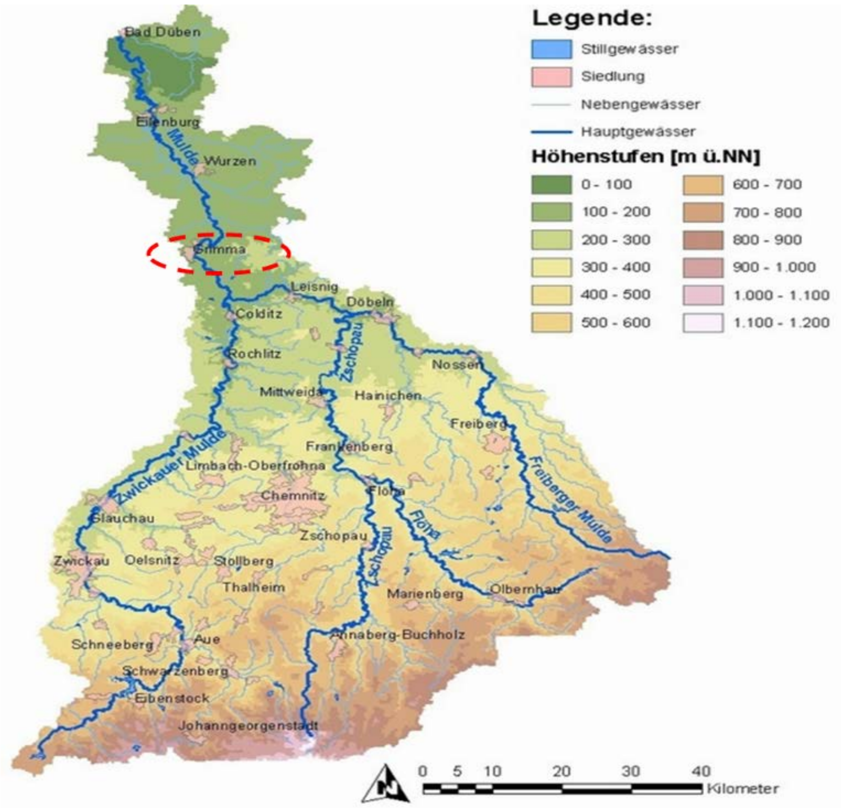

***Figure 1** Mulde River catchment (Flood-ERA project)*

The town of Grimma was founded around the year 1170 and received city charter in the year 1220. However, the first Slav settlements arose before the first documentary mention of the year 1200 (Grimma municipality, 2017). The first city wall was erected in the year 1232 and it safeguarded against raids and looting but also provided flood protection (Siedschlag, 2010). Only one sector of the wall still stands today, after it was destructed at the end of the 19th century.

Figure 2 Grimma town centre (Grimma.de)

Nowadays there are 26 remarkable buildings from five different art periods (Grimma municipality, 2017). The Grimma castle was erected during the 13th century, still standing today after several expansions and renovations. Another example is the former hospital of the Templerhof, a building from the year 1335. The famous town hall was built in 1442 and still stands today. Another distinguished building is the St. Augustine school, founded in the year 1550, where the 13th-century monastery used to stand, still functioning today. Furthermore, the Church of Our Lady has a Romanesque basilica, which was later refurbished several times, and nowadays contains a gothic altar. The Augustinian church, on the other hand, was finished around the 14th century. The first stone bridge was constructed in 1719, according to the plans of the Saxonian builder Mathias Pöppelmann. The bridge was severely damaged and partially collapsed during the 2002 flood event and was rebuilt in 2004, with a metallic arch. Given its cultural heritage, Grimma is an attractive spot for tourists.

The predominant constructions correspond to three or four storey buildings, built during the first half of the 20th century (Siedschlag, 2010). The historic centre comprises approximately 980 households (ibid.). Population in Grimma city centre in 2002 was approximately 2500 inhabitants (Mayor Berger, 2006). At the beginning of the year 2013, the inner city of Grimma had 2297 inhabitants (Grimma Municipal records, 2017).

Figure 3 *Grimma town centre, 2017*

The 13th of August 2002 the town of Grimma was affected by a severe flood, with water depths of around 3.5m (Siedschlag, 2010). More than 2000 people were affected and 1000 were evacuated, while 150 people needed to be rescued (Grimma Municipality, 2017). The flood caused damage to around 750 buildings. The total losses for Grimma (in addition to the old town, two smaller localities were affected) amounted to over 230 million euros, of which over 130 million euros were private damages (Grimma Municipality, 2017).

Grimma was again severely flooded during the 1st and 2nd June 2013 and all the residents were evacuated from the town centre, while some of them needed rescue (Bild, 2013). The flood caused damages of around 150 million euros in Grimma, with about 650 buildings damaged (Grimma

Figure 4 *Grimma city hall during the flood in 2002 (Welt.de, dpa / Jens Wolf)*

Figure 5 *Grimma city hall during flood in 2013 (UFZ)*

Municipality, 2017). These included two schools, one music school, a kindergarten, the city hall, the district court and the police station.

Figure 6 *Rescue during the 2002 flood (Welt.de, dpa/ZB)*

Figure 7 *Rescue during the 2013 flood (Welt.de, dpa/Jan Woitas)*

DISASTER FORENSIC APPROACH SELECTION

The state of the art on existing methodologies for disaster forensic analysis shows a multiplicity of approaches, motivated in part by the different objectives that each of them pursue, but not only. In fact, different disciplines are involved in the forensic endeavour, including forensic engineering, forensic geology and hydrology for hydrogeological disasters. Furthermore, some ad-hoc methodologies were developed for investigating the causes of "natural" disasters (e.g. FORIN, CEDIM'S Forensic Disaster Analysis and PERC), while some methods were "borrowed" from other disciplines, as in the case of incident investigation techniques used for technological accidents. Besides, both international (e.g. the IRDR with FORIN methodology) and national non-profit organizations (e.g. DKKV in Germany) defined their own approaches, as well as private organizations (e.g. Zurich Insurance Company with PERC). In addition, some countries have institutionalized procedures and programs aimed at the analysis of some aspects of disasters, more often on emergency management but not only (e.g. the United States with the Lessons Learned Information Sharing program and After Action Reports, Australia with quasi-judicial inquiries, the UK with independent inquiries and France with the "retour d'experience").

The starting point for this research is to understand the causes and contributing factors of a disaster, specifically of floodings, and its impacts from a holistic hazard research and socio-economic perspective. There is not one single factor that can be identified as a cause for the economic damages of a flood, but generally it is the combination of several factors that are accountable for its socio-economic impacts. Accordingly, the focus was set on the methodologies that were developed ad-hoc for investigating disasters ("Disaster forensics"), which study different aspects of a disaster and the elements that led to it.

The ad-hoc methodologies classified as "Disaster forensics" include Forensic Investigation of Disasters (FORIN by the IRDR), Post-Event Review Capability (PERC by Zurich Insurance Company), Detecting Disaster Root Causes (by the DKKV) and Forensic Disaster Analysis in Near Real-Time (by CEDIM). CEDIM's methodology (CEDIM, 2013) was designed to provide results useful for the emergency management phase, requiring "near real-time" data (i.e. data produced during crisis) and is, therefore, out of the scope of this work performed ex-post. On the other hand, the methodology developed by the DKKV (DKKV, 2012) is based on already available analyses of different aspects of the disaster made by experts as well as on expert interviews and does not make use of post-flood damage data. As a consequence, this approach is unsuitable for our analysis based on post-flood damage data.

The FORIN framework proposes the comparative case analysis as an approach for forensic research. It consists on a limited quantity of detailed analyses of several disaster events that can be geographically comparative (different locations and similar hazard event characteristics) or comparative in-situ (same place, repeat events or different hazard types) (Oliver-Smith et al., 2016). The Grimma floods case study is suitable for a comparative in-situ case analysis, for repeat flood events (2002 and 2013). Nevertheless, FORIN's objective is to identify the "root causes" of disasters, which are the more profound, fundamental causes that include culturally, socially, ideologically, pragmatically and politically assigned values and outcomes. However, the approximately ten year time-span between flood events is very little to be able to detect root-causes of this type.

Last, the PERC methodology (Venkateswaran et al., 2015) was initially developed and used for analysing flood events, making this approach particularly suitable for this kind of hazard. Furthermore, it follows a holistic and systemic analysis that includes flood damages and impacts data, probably due to their insurance background.

The approach for the Grimma case study was defined as a combination between the comparative in-situ analysis proposed by FORIN, in terms of a place-based detailed analysis of repeated events in the same area, and the PERC methodology. In particular, the PERC report was followed as a guidance for determining the different aspects and factors that required investigation and for presenting the results. The forensic investigation was thus applied sequentially to the two floods events in Grimma, with a comparative approach. The results of the analysis are presented next, following the structure suggested by the PERC methodology.

SECTION I: PHYSICAL CONTEXT

This part of the analysis is focused on the physical characteristics of the flood events (i.e. 2002 and 2013 floods) and in relation to other past events. These include results of hydrological, meteorological and hydraulic analyses, if relevant, as well as other collected data of the flood characteristics (e.g. water depth, velocity, the presence of sediments, etc.).

Hazard event 2002 and 2013

Different aspects were considered in order to compare the physical characteristics of the flood events of 2002 and 2013. These aspects include precipitation, return period, initial soil moisture, peak discharge, water depth, velocity, the presence of sediments/contaminants, flood duration, flooded area and presence of hydraulic infrastructure. For each aspect or element, some indicators were further selected to be able to objectively compare the two events (Table 1).

Table 1 *Indicators table for the hazard event*

<table>
<tr><th>Factor</th><th>Sub-category</th><th>Element</th><th>Indicator</th><th>Flood 2002</th><th>Flood 2013</th></tr>
<tr><td rowspan="19">Hazard event</td><td rowspan="4">Meteorology</td><td rowspan="4">Precipitation</td><td>6 hour maximum precipitation (Golzern 1) [mm]</td><td>53</td><td>21</td></tr>
<tr><td>12 hour maximun precipitation (Golzern 1) [mm]</td><td>87</td><td>32</td></tr>
<tr><td>24 hour maximum precipitation [mm]</td><td>149</td><td>58</td></tr>
<tr><td>48 hour maximum precipitation [mm]</td><td>176</td><td>90</td></tr>
<tr><td rowspan="5">Hydrology</td><td>Return period</td><td>Flood return period (Golzern 1) [years]</td><td>474</td><td>172</td></tr>
<tr><td rowspan="4">Initial soil moisture</td><td>Weighted average of antecedent precipitation (mean Wechselburg 1, Lichtenwalde 1, Nossen 1) [mm]</td><td>39</td><td>37</td></tr>
<tr><td>Ratio of initial river flow to mean annual flood (Wechselburg 1)</td><td>2</td><td>3</td></tr>
<tr><td>Ratio of initial river flow to mean annual flood (Lichtenwalde 1)</td><td>1</td><td>2</td></tr>
<tr><td>Ratio of initial river flow to mean annual flood (Nossen 1)</td><td>1</td><td>3</td></tr>
<tr><td rowspan="2">Hydrometry</td><td rowspan="2"></td><td>Peak discharge (Golzern 1) [m³/s]</td><td>2600</td><td>2040</td></tr>
<tr><td>Mean water depth in residential buildings [m]</td><td>4</td><td>2</td></tr>
<tr><td rowspan="3">Pollution</td><td rowspan="3">Presence of contaminants</td><td>Percentage of households with oil/petrol pollution [%]</td><td>56</td><td>40</td></tr>
<tr><td>Percentage of households with chemical pollution [%]</td><td>39</td><td>47</td></tr>
<tr><td>Percentage of households with sewage or feces pollution [%]</td><td>72</td><td>73</td></tr>
<tr><td rowspan="6">Hydraulic</td><td rowspan="3">Hydraulic infrastructure</td><td>Presence of protective infrastructure in city [Y/N]</td><td>No</td><td></td></tr>
<tr><td>Design return period of new infrastructure [years]</td><td></td><td>100</td></tr>
<tr><td>Degree of completion of new infrastructure [%]</td><td>0</td><td>50</td></tr>
<tr><td rowspan="2">Flood duration</td><td>Duration according to media articles and reports [days]</td><td>1 day</td><td>2 phases/2 days</td></tr>
<tr><td>Mean flood duration at household level [h]</td><td>35</td><td>50</td></tr>
<tr><td>Flooded area</td><td></td><td>City center</td><td>City center</td></tr>
</table>

Precipitation

Concerning precipitation, all the indicators (i.e. 6 hours, 12 hours, 24 hours and 48 hours maximum precipitations) show that the 2002 event was much more severe than the event of 2013. Furthermore, when compared to other important historical events, the precipitation in the 2002 flood always stands out, in all the pluviometers of the Mulde catchment in the Saxony State, for all the indicators and historical events. An example is provided in Figure 20 for the 6-hours maximum precipitation (the 12-hours, 24-hours and 48-hours maximum precipitation provide similar graphs).

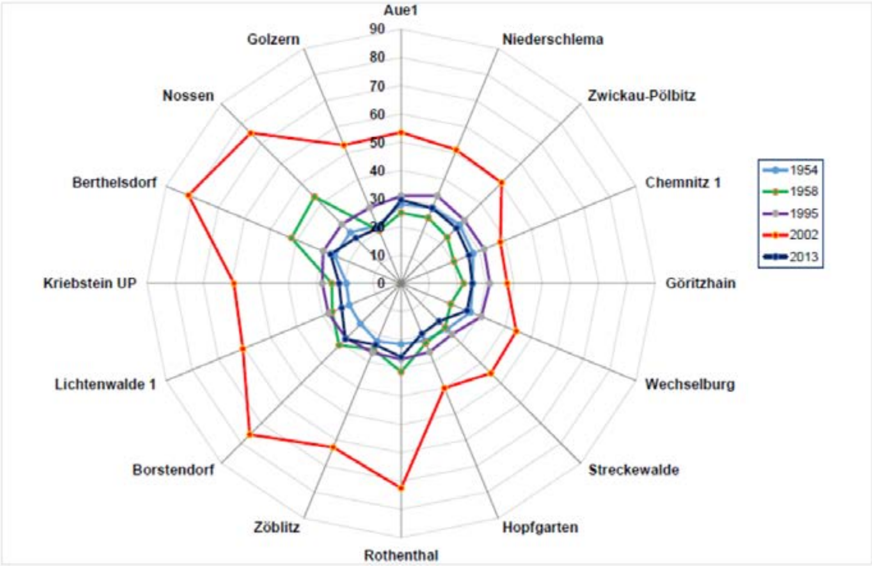

Figure 8 *6-hour precipitation [mm] in pluviometers in Saxony in the Mulde catchment for historical events (Schumann et al., 2016)*

A further difference in the precipitation between the 2002 and 2013 events is found in the precipitation pattern. In 2013, rainfall can be divided into two-time sections (May 30, 05:00 to 31 May, 18:00 and June 1, 07:00 to 3 June, 8:00 pm), as seen in Figure 9 (Schumann et al., 2016). Consequently, runoff increased until late hours of May 31st, with a temporary drop in the amount of rainfall, and then started to increase again, stronger and more prolonged than before, when rain resumed in the morning of June 1st and lasted until June 2nd and 3rd, depending on the location within the catchment.

In 2002, beginning in the afternoon hours of August 10, it rained an average of 11mm into the night hours (around 22:00). In individual areas, significantly higher rainfall values were recorded (e.g. Stollberg 45 mm and Eibenstock 25 mm) (Schumann et al., 2016). Overall, this precipitation was followed by a precipitation-free period, which lasted until the late afternoon hours of August 11. After that, intensive precipitation continued until the early morning hours of August 13. Between August 11, 17:00 and August 13, 20:00 hours, around 120 to 300 mm of rain fell in the river basin, depending on location.

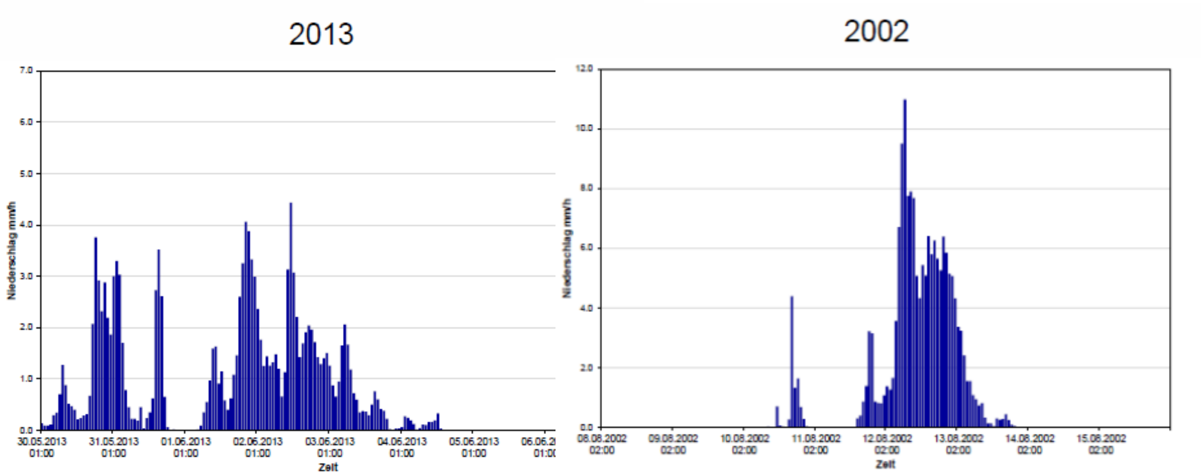

Figure 9 *Rainfall intensity [mm/h] in time for the 2013 and 2002 flood events in Pegel Bad Düben 1/Vereinigte Mulde gaging station (Schumann et al., 2016)*

Initial soil moisture

The initial soil moisture is a very important parameter that complements data on precipitation. The capacity of absorption of the soil depends among other factors on the initial soil moisture. This means that if precipitation occurs when the soil is saturated or near saturation, then very little water is infiltrated. Given that infiltration generally represents the major component loss of precipitation to surface runoff, an initially high soil moisture could explain a severe flood occurrence even if precipitation values are low.

Two indicators were selected for comparing the initial soil moistures of the two events: antecedent precipitation and the ratio of initial river flow to mean annual flood. Both flood events occurred during summer, therefore, the relevant antecedent precipitation in summer is, in general, less than 30 days due to evaporation (Schumann et al., 2016). In order to better compare the initial moisture conditions, a weighted sum of the pre-precipitation values was calculated. The 5-day pre-simulations were weighted by 0.5; the pre-precipitation that fell 6 to 10 days before the flood, was weighted by 0.3 and the pre-precipitation over 11 to 20 days before the event was weighted by 0.2 (ibid.). This weighted average of antecedent precipitation is very similar for the 2002 and 2013 events. On the other hand, the river flow before the start of the high water can be considered as a parameter for the initial moisture state and, in order to compare both events, the ratios to the summer average water discharge were calculated (Schumann et al., 2016). These ratios are more important for the 2013 flood event in comparison to 2002. In summary, the events of 2002 and 2013 were characterized by high pre-humidity (Schumann et al., 2016).

Flood Return Period and Peak Discharge

The return period of a flood event is determined according to the location in the catchment because it results from a flow frequency analysis of historical data. This means that return periods are estimated from historical data on recorded instantaneous flows, measured in gaging stations in different sections of the river. Therefore, the nearest gaging station was selected, i.e. Golzern 1, that is located downstream of Grimma. The 2002 flood event has a return period of 474 years, while the 2013 event corresponds to a 172 year return period (Schumann et al., 2016).

In addition, another indicator that was selected for the comparison was the peak discharge in the same gaging station, Golzern 1. In 2002, the peak discharge measured in Golzern 1 was 2600 m^3/s, while in 2013, 2040 m^3/s. Figure 23 shows the peak discharge ratios of 2002 and 2013 for all the gaging stations in Saxony. It is possible to see that in almost all cases the peak discharge in 2002 was bigger than the one of 2013, with a ratio that varies from 0.6 to 4.3.

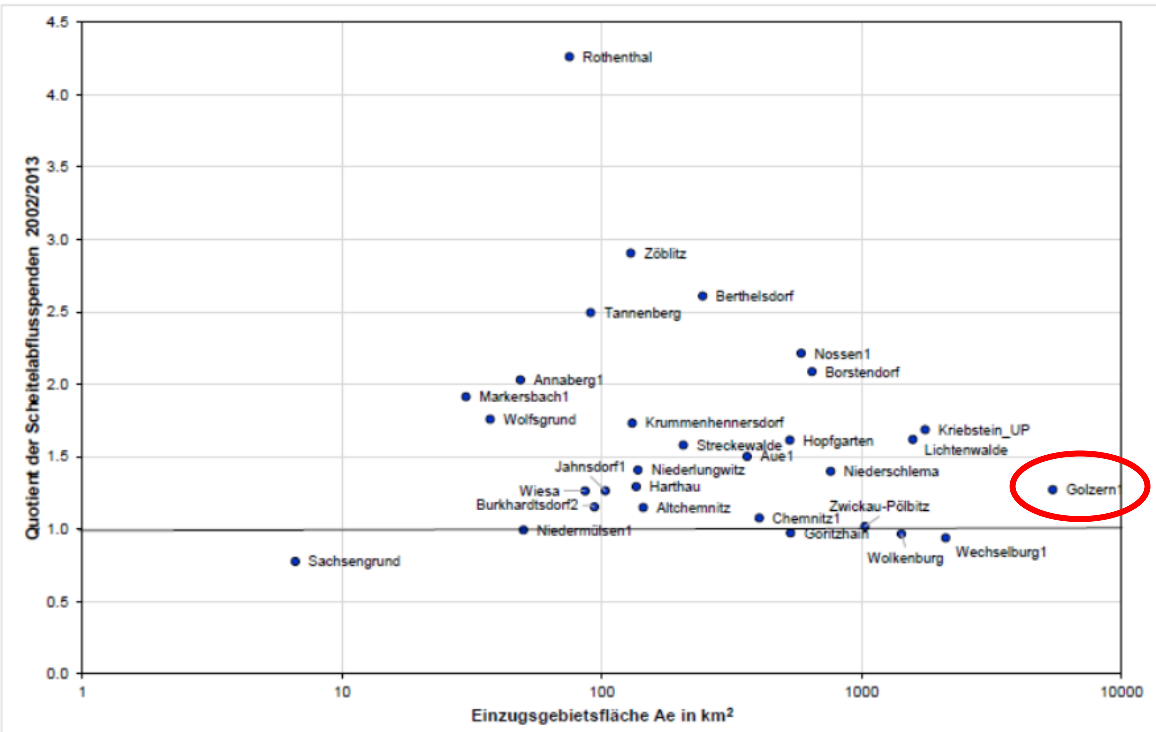

Figure 10 *Ratio of peak discharge in 2002 and 2013 in different gaging stations (Schumann et al., 2016)*

Water depth, velocity and contaminants

Available data regarding water depth corresponds to the data collected at a household level, through computer aided telephone interviews with residents, from the flood loss data of private households from University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung. Different statistics were calculated from the samples, i.e. statistical mean, median, 25th and 75th percentile, all represented in Figure 11. It is possible to note that even if there is more dispersion in the 2002 values, there is a clear upward shift of the 2002 values with respect to 2013 and, thus, the statistical mean is a good indicator for comparing both events.

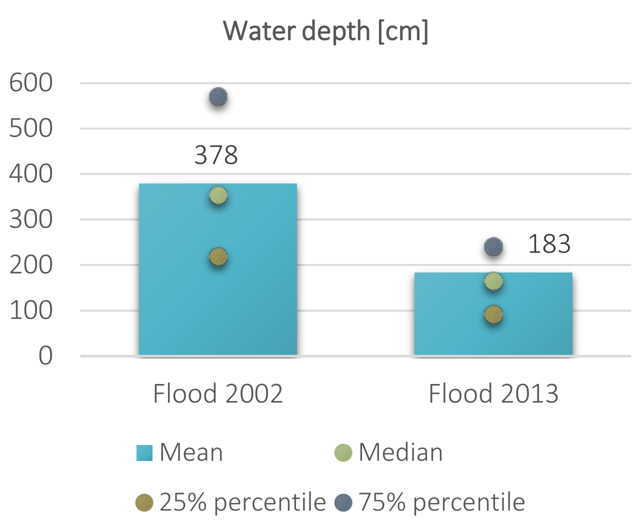

Figure 11 *Water depth [cm] in 2002 and 2013 floods*

The presence of contaminants of different types in floodwater can generate and aggravate damages. Consequently, the assessment of the presence of pollutants in both flood events is very important and it was based on available data at a household level. The selected indicators regard the presence of oil or petrol pollution, chemical pollution and, sewage and faeces contamination. Given that the samples do not contain all the households in Grimma, the selected indicators were measured as a percentage of households that reported each kind of pollution within the samples. These values show that around 70% of the households in the sample for both events reported the presence of faeces and sewage in floodwater. Other types of pollution were also important, with a higher percentage of oil and petrol affected households in 2002 (56% vs. 40%) and a slightly higher value regarding chemical pollution for 2013 (47% vs. 39%). However, these differences are considered small, of a similar order of magnitude. Concerning water velocity, on August 13, 2002, flow velocity in the city of Grimma was around 4-6 meters per second, while the water depth rose about 30 cm/hour (Grimma Museum, 2002).

Flood duration

In 2002 the flood lasted around 1 day (Siedschlag, 2010). On the contrary, the 2013 flood event had two phases. A first flood event started on June 1st and then the water level started to recede in the afternoon. In the night of June 1st and the morning of the 2nd, there was a second and more intense flood. Water level started to lower by the afternoon. By June 3rd, 2013, 8:00 am, the water level in Rivers in Saxony receded (Welt, 2013).

Data from the questionnaires at household level also show the difference in flood duration (Figure 12), depicted by the mean values (35 hours in 2002 and 50 hours in 2013). The higher dispersion in the flood duration values of 2013 was also expected, given that the event actually consisted of two phases, which affects reporting.

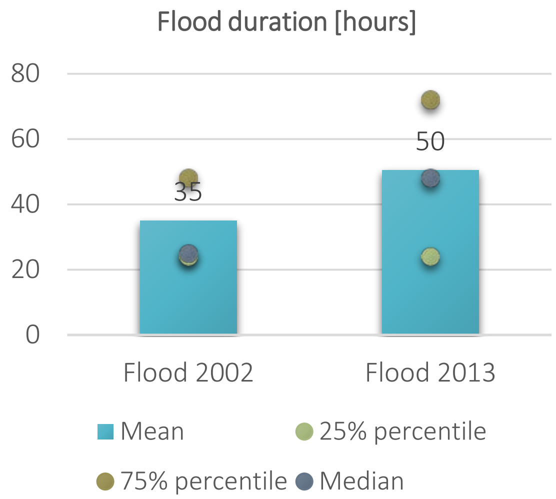

***Figure 12** Flood duration [hours] at households for the 2002 and 2013 floods*

Flooded area

Flooded areas in 2002 and 2013 were almost coincident due to the topography of the area, where the town centre is around 15m below surrounding areas. Hazard maps from the Elbe Atlas of the Mulde River in the Grimma area show that the flood-prone area for floods of 100 year return period and above almost coincide. Likewise, the location of some affected households from the telephone interviews (not presented here due to privacy issues) corroborated this fact and so did direct observations during fieldwork, where some of the flooded buildings had plaques and marks that indicated the level reached by flood water. A map elaborated with data by the Saxony State Office for Environment, Agriculture and Geology (Figure 13) shows that the flooded area in 2002 is slightly bigger than in 2013 for the town of Grimma.

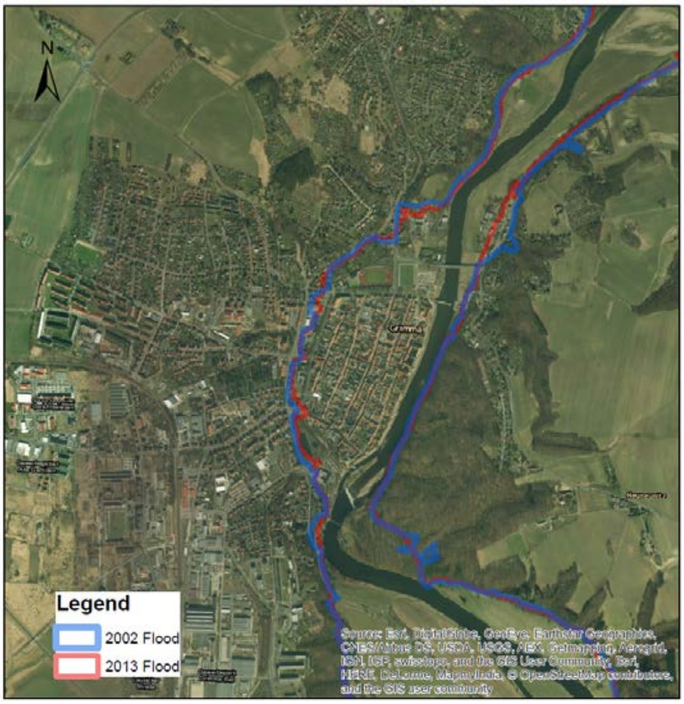

Figure 13 Map of the flooded areas in 2002 and 2013 (elaborated with data from the Saxony State Office for Environment, Agriculture and Geology, 2017).

Timeline of past floods

Historical records show that heavy floods occurred in Grimma in the years 1573 and 1771, while minor floods were expected every 20 years (Siedschlag, 2010). The last major flood before 2002 happened in Grimma in 1954, but the water level was not comparable either to the 2002 nor the 2013 floods (Figure 14 and Figure 15).

Figure 14 Water level of historic floods,
on the Großmühle building in Grima centre
(Landestalsperrenverwaltung des Freistaates Sachsen, 2006).

Figure 15 shows the most important historic floods and their respective water depths in Grimma, as represented in the Großmühle (large mill). Moreover, Table 2 shows the water level in the Mulde River in Grimma for some important flood events.

Table 1 *Water level in the Mulde River in Grimma during some flood events (Siedschlag, 2010).*

Flood year	**1573**	**1771**	**1858**	**1897**	**1932**	**1954**	**1958**	**1974**	**1995**	**2002**
Water level in the Mulde at Grimma [cm]	636	598	481	490	455	508	414	464	380	752

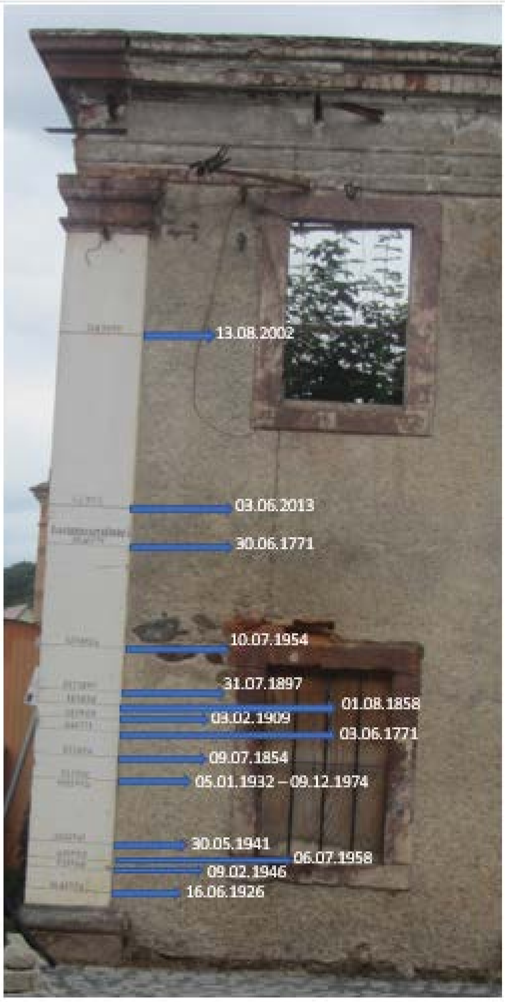

Figure 15 Historic flood levels in the Großmühle (large mill) in Grimma (2017, authors).

Figure 16 Pictures of the 1897 and 1954 floods in Grimma (Landestalsperrenverwaltung des Freistaates Sachsen, 2006).

The town of Grimma is located in an area that is at a lower level with respect to the surrounding land, as shown in Figure 17. This explains why floods are always confined to the area of the city centre.

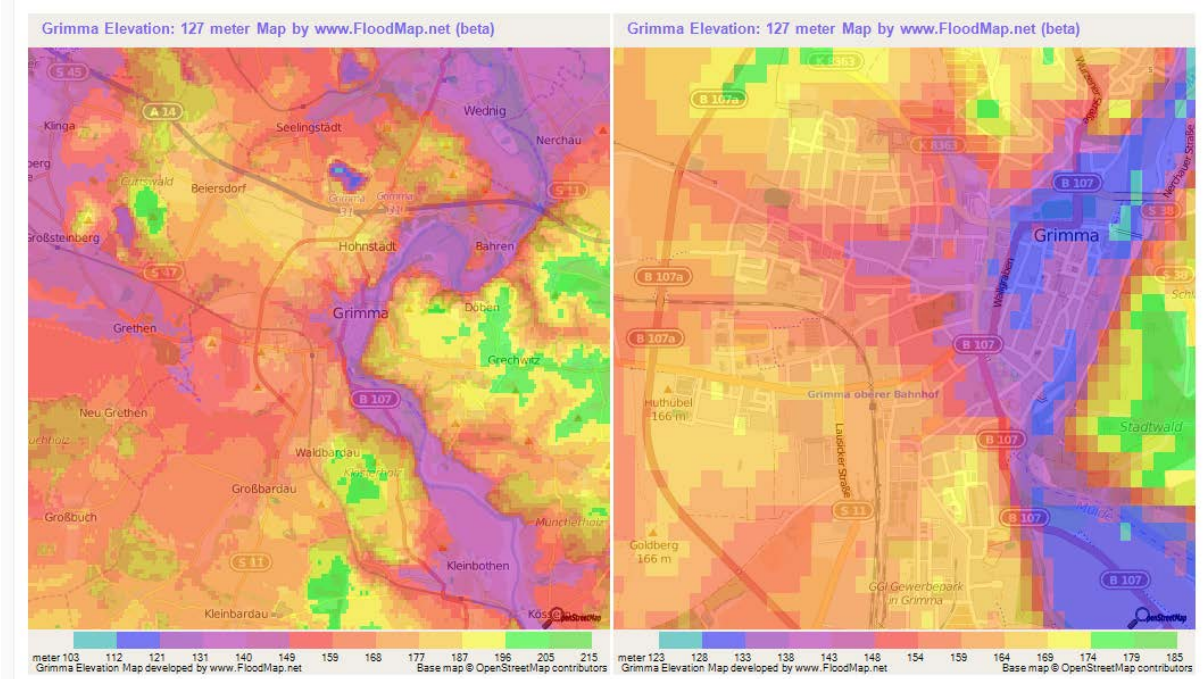

Figure 17 Elevation map of the town of Grimma. (Source: http://www.floodmap.net/Elevation/ElevationMap/?gi=2917325)

SECTION II: SOCIO-ECONOMIC DISASTER LANDSCAPE

Exposure and Vulnerability

This section includes an analysis of changes in exposure and built-up of assets, if relevant, as well as an analysis of groups of people, services and functions that might be vulnerable during floods.

Regarding the first point, the flood-prone and, thus, the exposed area of the town of Grimma coincides with the historic centre. Therefore, the built-environment mostly has not changed over the years, except for some possible minor refurbishments.

This is also true for the years between floods and corroborated by the satellite images reported below. There are minor changes that regard two parking lots, where in one case some trees where taken down and more park space was added for a supermarket in between the years 2000 and 2009. An important exception regards the police headquarters that were established around the year 2005 with federal funds. The police station serves the entire Grimma municipality, not just the historic centre, and consists of four buildings, located next to the Mulde River, south of the town centre (Figures 18, 19). One of these buildings was built at the beginning of the 20th century and was renovated to be part of the police station. After the refurbishments, it was flood proofed as part of one of the "flood wall" projects.

Mr Berger, mayor of Grimma, defined the new police station as a "victory for the city of Grimma" (interview 2006). He said he was very happy because it represented 300 new jobs for Grimma. Furthermore, he thought that the decision may seem dangerous, but that the area was as "risky" as the rest of Grimma and so if not, it made no sense to tell the citizens it was safe in 2002 for them to go back to their homes. Moreover, works were planned to protect the police station in the future. Concerning the police station construction, Mrs Guhlemann, Director of the Civil Engineering Division of the Urban

Planning Office of Grimma, said that the municipal council could only "advise" about these matters and that the area was already used and partially built in the past. People in Grimma were happy that these areas were used again and, regardless of their use, a flood protection wall had already been planned (interview 2005).

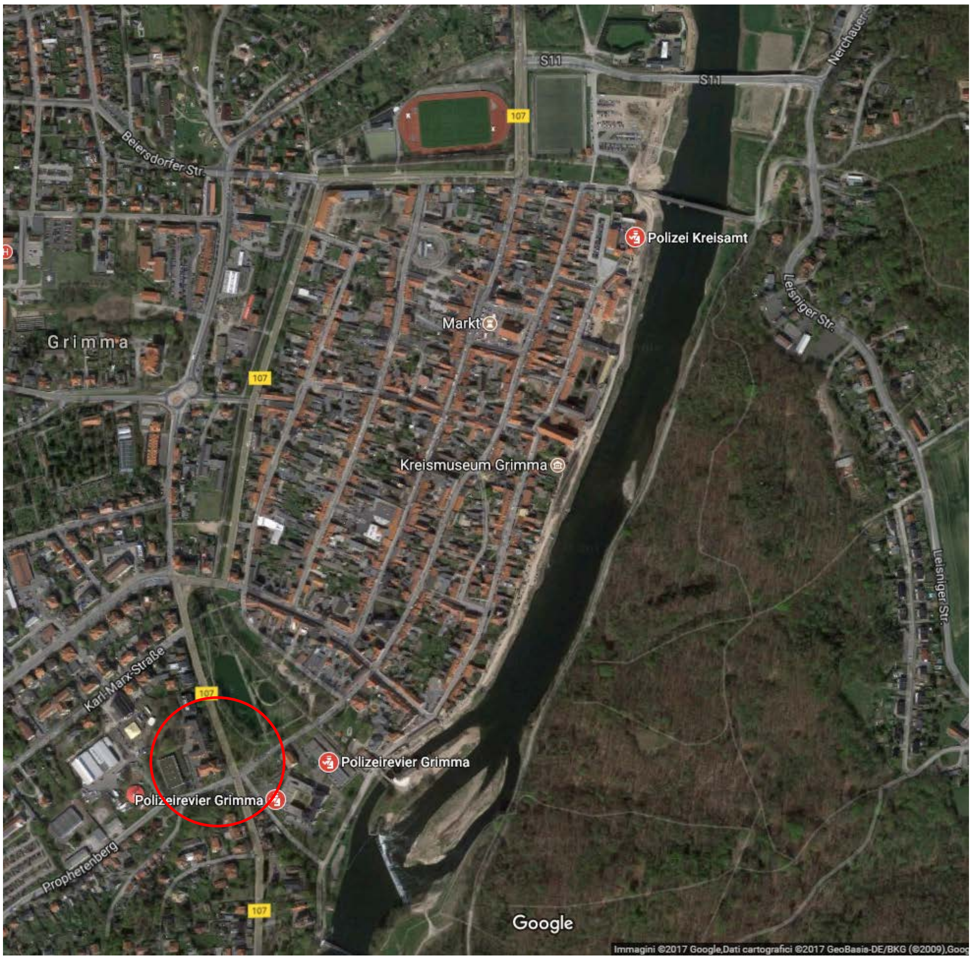

Figure 18 *New police station in Grimma town centre, indicated with a red circle (Google maps)*

Figure 19 *One of the buildings of the new police station in Grimma (https://www.polizei.sachsen.de/de/14607.htm)*

Figure 20 Satellite image of Grimma in 31-10-2000 (Google Earth2017)

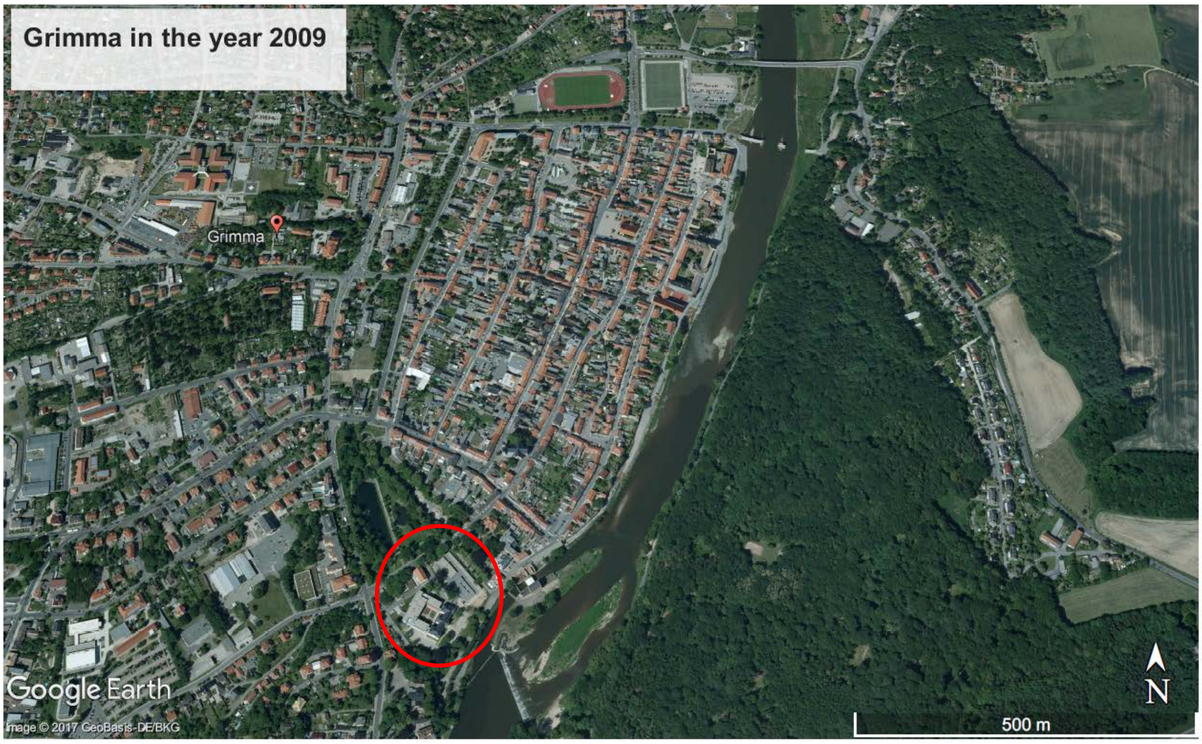

Figure 21 Satellite image of Grimma in 31-12-2009 (Google Earth2017)

Figure 22 *Satellite image of Grimma in 30-09-2013 (Google Earth2017)*

Even if the built-environment in its physical aspect mostly did not change from one flood event to the other, as shown by the satellite images (Figure 20, Figure 21, Figure 22), the buildings' function could have changed, and thus affecting their vulnerability. This is true regarding their physical vulnerability when considering a possible refurbishment in the interiors and contents, but mainly regarding their functional vulnerability. The 2002 flood put the town of Grimma under the media's spotlight, both local and international, as shown by articles in newspapers at that time. An example is an article on CNN of August 20, 2002, where different damages in Grimma are reported. Furthermore, even the mayor at that time recognised the focus that the media had on Grimma. This fact, plus the quick reconstruction and refurbishment of the buildings to an even better state than before the flood, made the city more attractive to tourism. All the buildings were renovated, even the ones that had never been refurbished before (Mrs. Guhlemann in the interview 2005).

In the words of Grimma's mayor, Mr Berger, in an interview in 2006:

"We honestly have to recognize, that Grimma rather benefited from the historic flood. We received over 250 million Euros of direct investment in the affected areas and can see as a result an unprecedented homogeneity of reconstruction of building stock. Almost every building in the historic centre is refurbished (…) during the last three years we could increase tourism-related revenue by around 30 %"

The increase in tourism could have altered the functions of some buildings, from residential to commercial and touristic services. Historic information on these activities is not available. Concerning hotel services, nowadays there are two hotels and one pension in the historic centre. The gastronomic offer comprises 18 restaurants and bars in the town centre (Figure 23). Moreover, other touristic attractions in the centre include the Kreismuseum, the Frauenkirche church and other historic buildings.

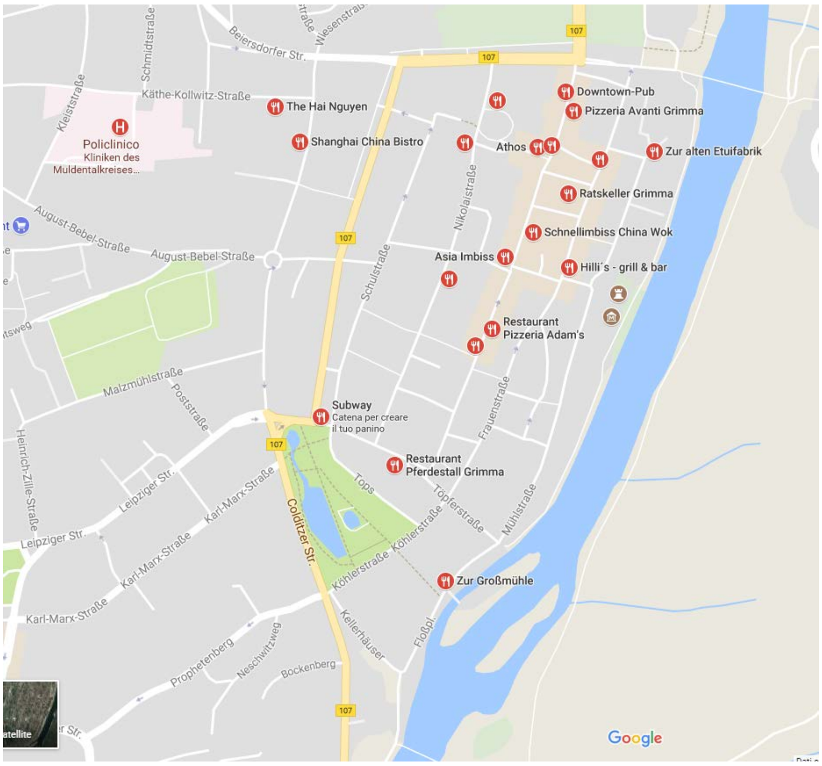

Figure 23 Restaurants and bars in Grimma centre 2017 (Googlemaps, 2017)

All of these activities and functions are under risk of flooding, which means that tourism can be very affected in case of a flood. If a flood occurs during the day, there could be a considerable number of tourists in the area. The situation would be even worse if it happened on holidays.

Besides tourism services, there are other commercial activities that are also present in the area such as pharmacies, supermarkets, bakeries, a cinema and shops of different kinds. Concerning potentially affected vulnerable groups, there is a retirement home inside the flood-prone area and another one just outside the limits of this area. Regarding children, there are two schools, a music school and a kindergarten in the historic centre, while there are another school and two kindergartens just outside the flood-prone area (Figure 24).

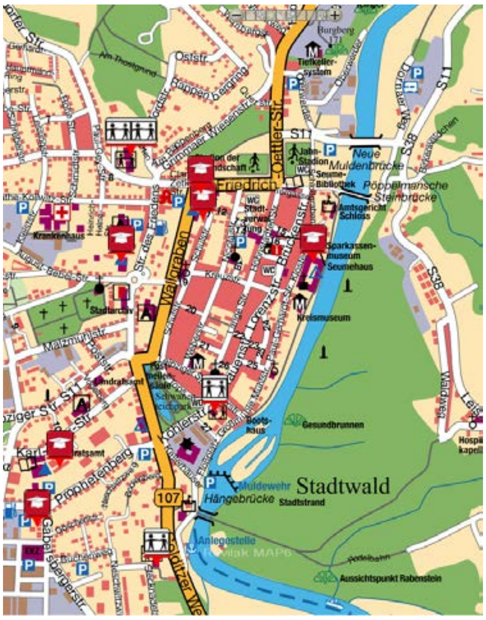

Figure 24 Schools and kindergartens in Grimma (Grimma municipality, http://grimma.bemap.eu/)

As mentioned above, the new police station is also in the flood-prone area, as well as another existent police office in the northern part of the town centre. The fire station is located just outside the limit of the flood-prone area. In the case of a flood, these functions could be affected, when needed the most.

Prospective and corrective risk reduction and preparedness

Institutional Landscape: Key actors of the disaster management system

Governance in Germany is defined by the federal system, established after the Second World War. The federal states are responsible for several sectors, such as education, infrastructure, transport and environmental resources (Uyttendaele et al., 2011). Federalism in Germany consists of a decentralised political system with a three-level administrative structure that possesses constitutional autonomy: The Federation ("Bund") and the federal state ("Länder") issue laws and regulations, while the district (Kreis) and municipality ("Städte und Gemeinden") implement them (ibid.). Consequently, flood risk management is the responsibility of the states, which need to respect the general conditions established by the federal level. Both the states and the local authorities are in charge of implementing the actual measures (Walker et al., 2010).

In Saxony, there are two authorities responsible for flood management: The State Reservoir Administration (LTV), responsible for structural measures, and the Saxon State Agency for Environment and Geology (LfUG) in charge of non-structural measures (Walker et al., 2010). After the 2002 flood, the Saxon State Ministry of the Environment and Agriculture (SMUL) initiated the development of a new flood protection concept for the Mulde River and put the State Reservoir Administration (LTV), responsible for structural measures, in charge of designing and implementing it (Walker et al., 2010). This flood protection concept takes different protection goals into account according to the type of uses and population density of the areas to protect. It also prioritizes structural measures based on their meaning for the communities at risk (ibid.). Besides these structural measures, the SMUL initiated the development of an early warning system, which is managed by the Saxon State Agency for Environment and Geology (LfUG) (Walker et al., 2010).

Walker et al. (2010) explain that no integrative view was followed in flood protection. After the 2002 flood, important financial support was available by the European Union, the Bund (federal state) and The Free State of Saxony (Walker et al., 2010). Most of these funds were destined to the LTV, responsible for structural measures, thus favouring the implementation of structural measures over non-structural ones, which are developed by the LfUG (ibid.).

On the other hand, Civil Protection is prescribed by the German Constitution, the Basic Law. The term "civil protection" denotes all emergency management tasks and measures taken by federal, state and local governments and reflects a horizontal approach, regarding the protection of the population against all kind of natural and man-made disasters (Federal Ministry of the Interior, 2017). Germany's constitution assigns responsibility for civil protection tasks as follows: The federal states (Länder) are responsible for disaster management, while the Federation is responsible for civil protection and disaster assistance (Federal Ministry of the Interior, 2017).

The Federal Ministry of the Interior (BBK) is responsible for matters related to civil protection and disaster assistance and offers a wide range of services (e.g. information-sharing, coordination, resources management and crisis management exercises) for authorities at all administrative levels, organizations and institutions involved in civil protection (Federal Ministry of the Interior, 2017). In accordance with the Constitution, the federal states have enacted their own laws in these areas on police-led threat prevention, rescue services, fire protection and fire services as well as disaster control and management (ibid.).

Physical flood protection structure: The new flood wall

When the flood occurred in 2002, Grimma did not have any flood protection infrastructure. Historically, the old medieval urban wall offered some flood protection, but was partially destroyed over the years and lost its capabilities. There is a portion of the wall still standing today. Besides riverine floods, the town of Grimma suffered from groundwater flooding, even when there was no riverine flood. According to Mrs Guhlemann (2005), historically there were no technical instruments to prevent this kind of flooding and that is why Grimma did not have flood protection in 2002.

After the flood, different measures were defined for flood protection in the Mulde River. One of these structural measures was a solid protection wall in front of the historic town in Grimma, with an initial study and preliminary planning in 2003 and 2004, which had been given a high priority within the prioritization scheme (Schanze et al., 2008). The protection goal of this measure was for floods up to an exceedance probability of 1/100. Nevertheless, the initial project was rejected by Grimma's population and some members of the municipality because they claimed that such a measure ruined the historical setting and cultural heritage of the town (ibid.). These problems delayed the construction of the floodwall for years. In order to find a solution, the TU Dresden University with a team of architects and preservationists performed a study and proposed a solution with several projects that integrates the protection into the old town wall, with the original protection goal. This study included physical and numerical modelling, between December 2005 and October 2006, considering different scenarios as well as the hydraulic impacts of the urban design variant (hochwasserschutz-grimma.de, 2017). Of importance for the acceptance and functioning of the flood protection structure in the urban sense were public transit from the city to the water, included as part of the new solution design (ibid.).

Finally, after another five unsuccessful complaints, in August 2007 the works began and were expected to be finished by 2017 (Spiegel, 2013). However, the actual cost calculations for this compromise solution are very much higher, 40 million €, (Spiegel, 2013) than the cost calculations for the initially planned protection wall, of around 12 million € (Schanze et al., 2008). As corroborated during fieldwork in June 2017, some projects of the floodwall were still under construction.

The solution is divided into 5 projects (Figure 25):

- Project 1 – From the street "Kellerhäuser" to the north end of the boathouse.
- Project 2 - Old City Wall from the boathouse (Bootshaus) to the monastery church (Klosterkirche).
- Project 3 - Klosterkirche to Pöppelmann Bridge.
- Project 4 - Pöppelmann bridge to the end of the natural rock massif.
- Project 5 - Sealing wall and subsoil seal.

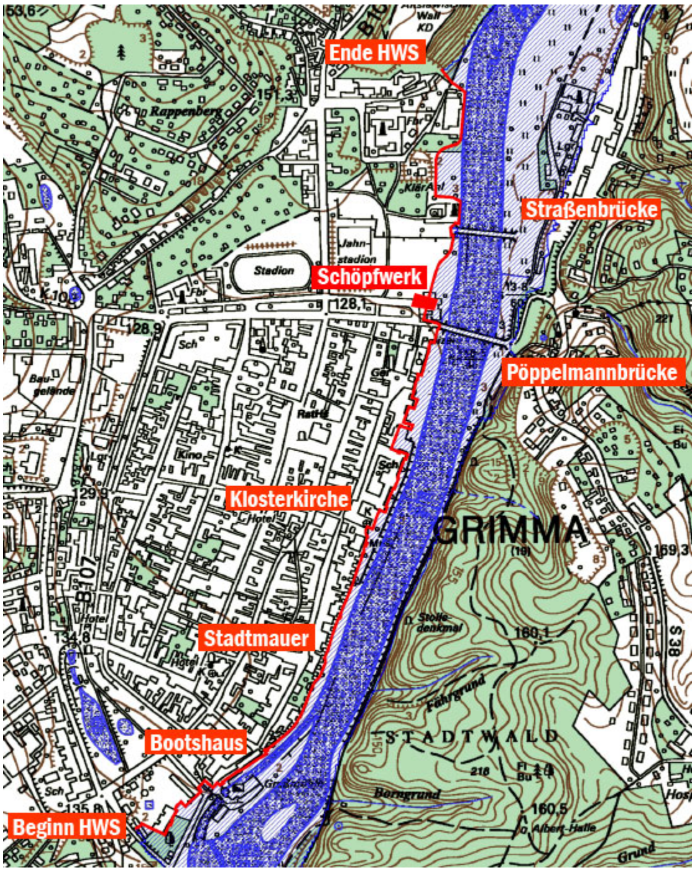

Figure 25 Flood wall projects for the town of Grimma (hochwasserschutz-grimma.de, 2017)

The flood protection system thus runs directly in front of the first waterfront building facade and wall sections and is partially integrated into it. The following elements are used:

- Free wall
- Wall integrating existing wall and buildings
- Floodproofing of existing buildings
- Subsoil and sealing wall

Project 1 (Figure 26) includes the area from the street "Kellerhäuser" to the north end of the boathouse. The police station buildings, the new garages, a restaurant, the old rye mill and the boathouse will be surrounded by the walls. The short sections between the buildings are protected by free-standing walls. The height of the wall varies between 1.5 m (new police building) and about 4 m (rye mill/ boathouse) (hochwasserschutz-grimma.de, 2017). The historic building that is part of the police new Headquarters, built around 1900, will be integrated into the flood protection scheme and, thus, floodproofed. Another important element of Project 1 is the floodgate, next to the old rye mill (Figure 27).

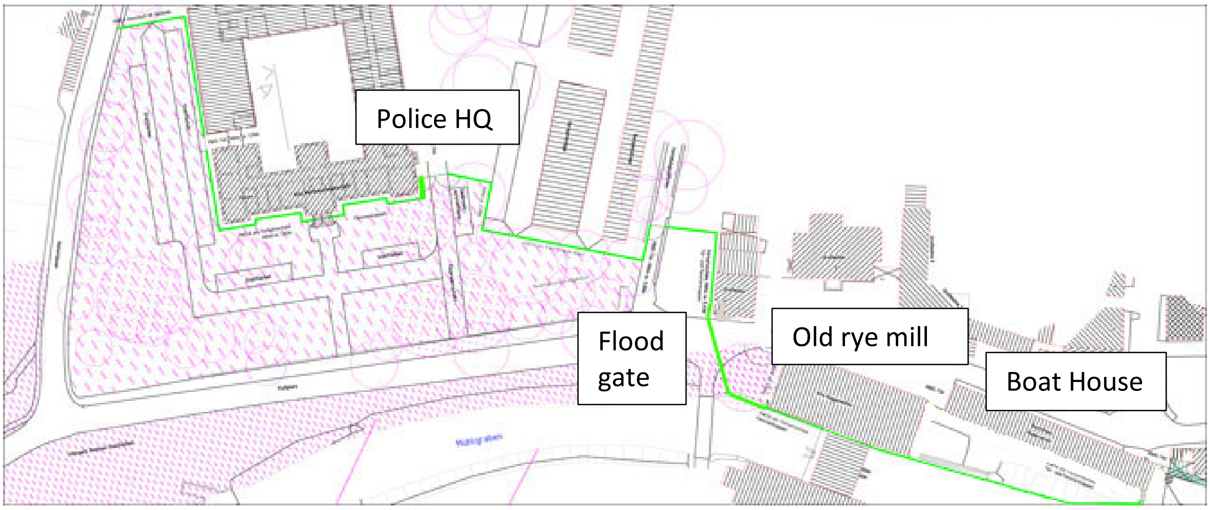

Figure 26 *Project 1, floodwall (hochwasserschutz-grimma.de)*

Figure 27 *Floodgate, part of the floodwall Project 1*

In Project 2, the old city wall from the boathouse to the monastery church, the new wall was erected directly in front of the existing city wall. The height of the floodwall varies between 3.5 m and 4.5 m. Three passageways were left on the wall to guarantee access to the river (Figure 40). All three passages are equipped with a high-water protection gate on the waterside so that the waterways can be closed at

Figure 3 *New floodwall, part of Project 2, with passageways for accessing the river and allowing a view (2017, authors)*

short notice in case of imminent floods (hochwasserschutz-grimma.de, 2017).

Figure 4 *Floodwall, Project 2, under construction (June 2017, authors).*

Project 3 covers the area between Klosterkirche (Monastery church) and Pöppelmann bridge (Figure 30). In this case, the layout takes into account the buildings.

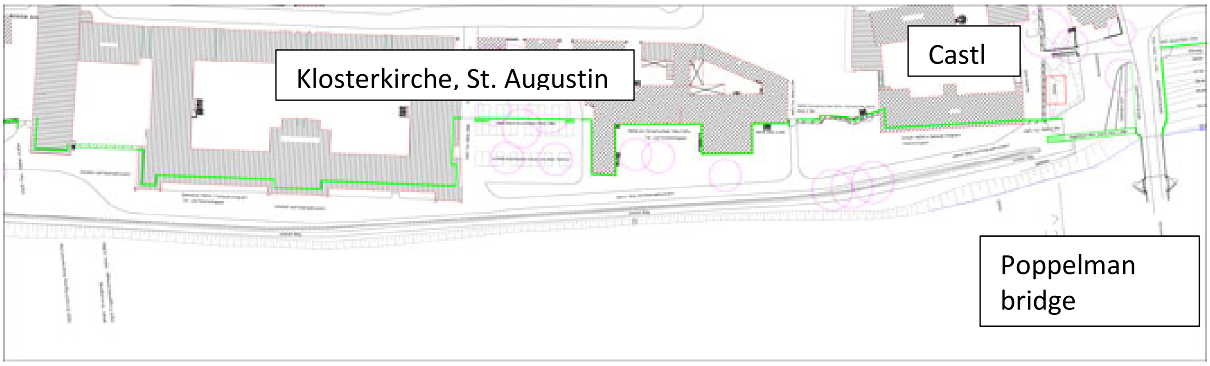

Figure 30 Project 3 layout (hochwasserschutz-grimma.de)

The project contemplated the historic buildings, the monastery church (current St. Augustin School) and Grimma's castle, to be renovated and flood-proofed in order to take part in the floodwall.

Project 4 begins at the Pöppelmann Bridge and leads to the end of the natural rock massif north of Grimma. A freestanding reinforced concrete wall is envisaged; on the north side of the Pöppelmannbrücke, the protection system runs inland to the foot of the bridge and then swings to the North to meet the new Mulde bridge in a line that is curved towards the river. The height of the flood protection system varies between 2,5 m and 3 m (hochwasserschutz-grimma.de, 2017). This project is still under construction (as to June 2017) and is expected to be finished by 2018 (LVZ, 2016) (Figure 31).

Figure 31 Floodwall, project 4, under construction (June 2017)

Project 5 comprises the sealing wall, the underground barrier and the groundwater communication system during the construction of the flood protection system (projects 1 to 4). A sealing wall of bored piles along the flood protection system, which also serves as a foundation for the floodwater protection wall beyond the sealing effect, will be erected to avoid underground infiltration to the urban area. To ensure that the natural groundwater flow direction from the inside to the river is not interrupted, a groundwater communication system is to be constructed with the sealing wall which allows a normal drainage of the groundwater. It is a very complicated project that involves also the construction of a pumping station. It was still under execution as to June 2017.

By the time the 2013 flood occurred, most of the projects had already begun. It is possible to say that the flood wall was "50% ready", with 20 Million euros spent of the planned 40 Million (Spiegel, 2013).

The Local Flood Warning System

Part of the donations received after the 2002 flood was used by the town council of Grimma to set an autonomous local early warning system, motivated by the lack of a timely flood warning in 2002 (Schanze et al., 2008). The early warning system consists of the following:

- Sirens and a central flood announcement system.

  Four sirens were installed on the roofs of the following buildings in Grimma's inner city:

- School St. Augustin
- Johann-Gottfried-Seume High School
- Primary school / Secondary school in Wallgraben 23.
- LangeStraße 15

In the case of danger, a siren sound is heard, followed by a gong. Then the announcement, which is always repeated, takes place. The sirens can also be used for up to 7 days in the event of a power cut. The siren will sound for the first time at a level of 3.00 m above normal. Further information is provided with the sirens and the announcement system when the event continues to unfold, and the siren also gives the "all-clear" with a continuous tone (Grimma Municipality, 2017).

- 24-h information in situations of approaching flood conditions in the regional program of Muldental-TV (local TV station).

Muldental-TV is used in the case of potential floods with up-to-date information. If necessary, the transmitter will immediately interrupt its current program. From a level of 3 m above normal, updated messages will be transmitted on the screen regarding the current water levels and the forecast ones, the traffic and parking situation, possible evacuation measures and the end of flood warning.

- Autonomous SMS - information network.

Any resident or owner of a house or business in the old town can use this system free of charge by registering to the service. At the beginning of 2009, 420 people were registered in the SMS warning system of the city (Siedschlag, 2010).

- A river gauge camera, live streaming on the internet.

The level camera on Steinbaum monument went into operation on May 12, 2005, to complete the warning system scheme.

- House threshold measuring.

Citizens can access the internet to monitor water levels via the level gauge camera and then compare them with the height of their doorstep, and then know when the flood might reach their home.

The warning system required investment costs of 148,000 € and annual running costs of around 4,000€ (Schanze et al., 2008). This local warning system works in addition to the Saxon warning system, run by the Saxon State Agency for Environment and Geology (LfUG) (ibid.). This local early warning system is "tolerated" by decision makers on the federal level, with critics with respect to the lack of correspondence between warning levels and thresholds (Schanze et al., 2008).

Precautionary measures at the household level

The interviews of affected households contained data regarding the precautionary measures that were taken before the respective flood event. It is important to note again that the interviews did not cover all the affected households but a small sample that may or not be representative of the whole of Grimma town, either of all the flooded households. Nevertheless, these data are still useful to explain or interpret damages within the samples. Figure 32 shows the percentage of households that took at least one precautionary measures before the 2002 flood and the 2013 flood events, respectively.

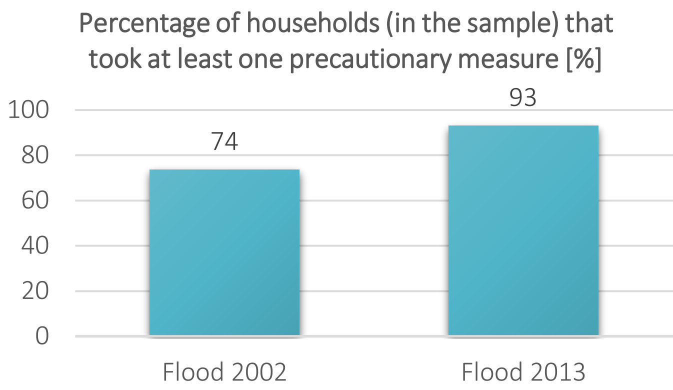

Figure 32 *Percentage of households that took at least one precautionary measures before the 2002 and 2013 flood events.*

The precautionary measures mentioned in the interviews were of different types. These measures were classified in order to understand the influence that they may have had in the damage to the building and contents. Furthermore, given that the measures included in the interviews in 2002 and 2013 differ, this classification allows comparison. Measures for preventing or reducing the damage to contents are classified as "content" measures, measures for reducing damage to the building are "building" measures and measures for reducing the hazard intensity are termed "hazard" measures (Table 3 and Table 4).

Table 2 *Precautionary measures classification for the 2002 flood event.*

Measure type	Precautionary Measures (2002)
CONTENT	Movable contents taken to upper floors.
BUILDING	Avoid valuable, permanently installed interior fittings in lower floors, but use water-resistant or easily renewable building and construction materials.
	Move the heating system and/or the electrical supply systems to higher floors.
	Change the heating system type or provide the oil tank with flood protection.
HAZARD	Improvement of the basement and building hydraulic stability.
	Mobile elements that prevent water from entering the building (such as sands bags, small local flood protection walls).
	Move to a less hazardous location.

Table 4 Precautionary measures classification for the 2013 flood event.

Measure type	Precautionary Measures (2013)
CONTENT	Movable contents taken to upper floors.
BUILDING	Avoid valuable, permanently installed interior fittings in lower floors, but use water-resistant or easily renewable building and construction materials.
	Move the heating system and/or the electrical supply systems to higher floors.
	Change the heating system type or provide the oil tank with flood protection.
HAZARD	Improvement of the basement and building hydraulic stability.
	Use of valves to prevent backflow.
	Mobile elements that prevent water from entering the building (such as sands bags, small local flood protection walls).
	Water pumps installation.
	Move to a less hazardous location.

The percentage of households within the sample that took at least one precautionary measure concerning each category was calculated (Table 5). Furthermore, measures directed to reduce the intensity of the hazard are meant to reduce both the damages to the building and the contents. Consequently, they were considered also with both categories.

Table 3 Percentage of households within the sample that took at least one precautionary measure during the flood events

	Percentage [%] of households that took at least one precautionary measure for				
	Content	**Building**	**Hazard**	**Content+Hazard**	**Building+Hazard**
Flood 2002	21	32	5	21	32
Flood 2013	24	48	31	41	62

Regarding the number of measures taken to reduce both the hazard intensity and the damage to contents, in both cases, before the 2002 flood and the 2013 flood, the number of measures ranges from 0 to a maximum of 3.

SECTION III: WHAT HAPPENED?

Flood protection infrastructure performance

When the flood occurred in 2002, Grimma did not have any flood protection infrastructure. Historically, the old medieval urban wall offered some flood protection, but only one small section is still standing. The new flood wall was under construction while the 2013 flood occurred, with 20 million euros spent over a final sum of 40 million for the whole project (Spiegel, 2013). Even if the execution of the flood wall was halfway through, at least in terms of expenditure, the performance of what had been built was non-existent. The project was conceived to work as a whole, even if the execution was piecemeal. Section I also showed how the flooded area in 2013 did not change with respect to the 2002 flood event, strengthening this fact.

Mayor Matthias Berger stated in an interview after the 2013 flood: "With a finished flood wall, water would have stayed out 100 per cent" (Spiegel, 2013) and that "a flood like the one we just had wouldn't have hit Grimma if we'd had a flood protection system available" (DW, 2013). Mr Axel Bobbe, in charge of Flood Protection projects in the Leipzig district, said that "the flood that has come upon us now, comes four years too early", referring to the fact that works were to be finished by 2017 (ibid.). Moreover, Stanislaw Tillich, Prime Minister of the Free State of Saxony, said after his visit to Grimma about the consequences of the floodwater protection wall: "I am inclined to put an end to the co-determination of citizens in such an important project" (Spiegel, 2013).

Figure 33 *New floodwall, photo taken across the Mulde River by the authors (June 2017)*

Disaster damages and impacts

The total losses for Grimma due to the 2002 flood (in addition to the old town, two smaller localities were affected) amounted to over 230 million euros, of which over 130 million euros were private damages (Siedlag, 2010).

A total of 750 buildings in Grimma centre and affected localities were damaged (Grimma Museum, 2002). Five buildings collapsed during the flood, while 24 had to be demolished shortly afterwards.

A total of 50.000 cubic meters of waste had to be removed from the inner city the first week after the flood.

Damage to infrastructure includes two severely damaged bridges. Two arches of the Poppelmann bridge collapsed, while the Hangerbrücke was heavily damaged (Grimma Museum, 2002) due to debris. According to CNN (2002), the top of Hangerbrücke Bridge (suspension bridge) was jammed with straw and a pile of debris that included even a portable toilet. Moreover, 2300 meters of roads were damaged, while 3500 meters of footpaths were destroyed.

Water contamination was a concern after the 2002 flood due to the presence of dead animals and sewage in flood water. There was a warning about hepatitis, but there were no reported cases of people being affected (CNN, 2002). Drinking water was super chlorinated and according to the authorities it was drinkable for adults, even if not recommended, but not suitable for child consumption (ibid.).

Besides the damages and negative impacts, there were also some positive ones. According to Grimma's mayor, Mr Berger recognized that "Grimma rather benefited from the flood" (Interview Flood-ERA Project, 2008). Almost every building in the historic centre was refurbished and during the three years that followed the flood, tourism-related revenue increased by around 30 % (ibid.).

The 2013 flood caused damages of around 150 million euros in Grimma, with about 650 buildings damaged (Grimma Municipality, 2017). These included two schools, one music school, a kindergarten, the city hall, the district court and the new police station (Figure 34).

Figure 34 *New police station flooded during the 2013 flood (Colditzer-tageblatt online newspaper, 2013)*

Cleaning of the city was completed in 5 days, with around 35.000 cubic meters of waste removed (LVZ, 2013).

In the morning of June 2nd 2013, access roads were blocked by water (Bild, 2013). Nevertheless, they suffered minor damages and were covered in mud (DW, 2013). Mayor Berger said some "small, specific things" were missing from the streets (ibid.).

There were power outages reported on the afternoon of June the 2nd when the energy supplier Envia failed to serve 14.000 customers in East Germany (Welt, 2013). Water, electricity and gas supplies were off in Grimma centre and restored during the following 5 days after the flood (LVZ, 2013).

The suspension bridge over the Mulde river was covered with flotsam and unpassable, though it was not damaged (Figure 35).

Figure 35 Suspension bridge covered in debris on June 6th 2013 (DW, 2013)

Tourism losses in Saxony were reported as early as the morning of June 3rd, 2013: "The inner-city hotels of Grimma are no longer receiving guests" (representative of the Tourism Marketing Society in Saxony, as quoted in the newspaper Welt, 2013). Providers of holiday apartments were also affected, with the decrease in accommodation and information requests (ibid.). Tourism is an important economic activity in the area (Welt, 2013).

Damage to the residential sector: 2002 and 2013 floods

The data used in this section are the flood loss data of private households from University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung (from 2002 and 2013). Damages to the residential sector from the 2002 and 2013 floods are compared as a means of researching their causal processes, as suggested in FORIN (Oliver-Smith et al., 2016). Figure 36 shows the damages to the building (i.e., everything not detachable, such as the structure, finishes, heating/gas/water systems) expressed in monetary values for both flood events. Monetary values from 2002 were corrected for inflation to 2013.

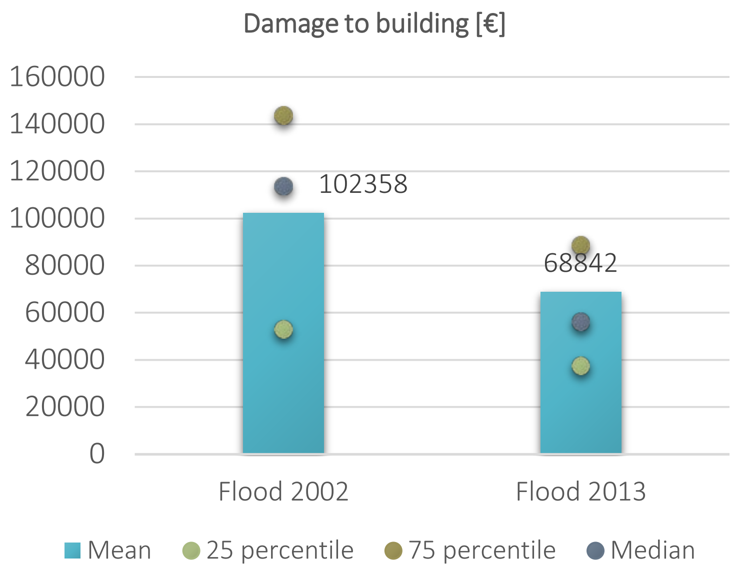

Figure 36 Damage to buildings (corrected for inflation to 2013) within the samples for the 2002 and 2013 floods

As it would be expected, considering that the water depth was higher during the 2002 flood, as analysed in a previous section, damage to the building statistics of 2002 are higher than those of 2013. Nevertheless, damage to household contents does not follow the same trend (Figure 37). The fact that damage to contents is very similar in both events could be explained by the important difference in flood duration.

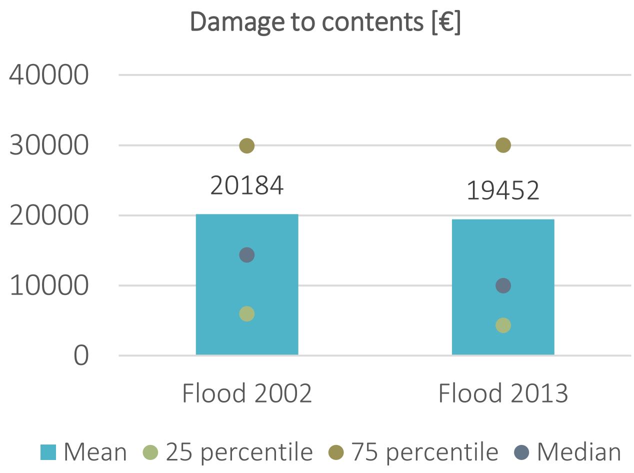

Figure 5 Damage to household contents (corrected for inflation to 2013) within the samples in 2002 and 2013 floods.

In order to rule out other factors that could have determined a similar damage to contents during the 2013 flood event with respect to 2002, different hypotheses were generated and analysed, following the phases of accident investigation (ESReDA, 2009). These hypotheses were generated by the authorstabl based on the knowledge on flood damage mechanisms.

First Hypothesis: "In the 2013 flood there were more buildings in the sample with a flooded basement"

The first hypothesis or assumption to be tested is that in 2013 there were more buildings in the sample with a flooded basement. If this were the case, then basements would be flooded, and their contents damaged, which would add to the total damage to contents, even with a lower water depth.

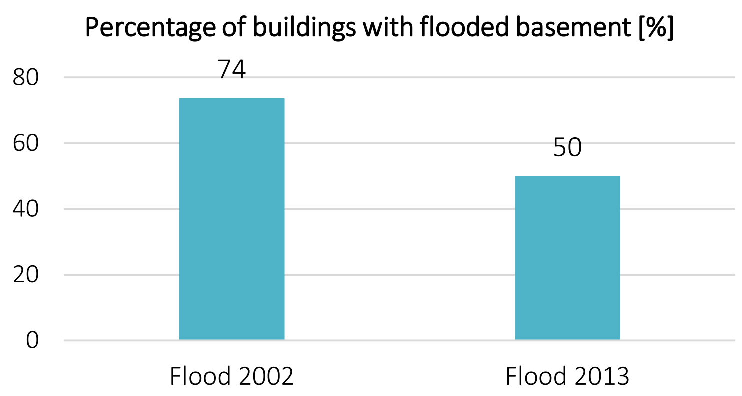

Figure 38 Percentage of buildings within the sample with flooded basements in the 2002 and 2013 floods

Figure 38 shows that this was not the case. Actually, in the 2002 flood sample, 74% of the buildings had a flooded basement, while in 2013, only 50%. This evidence would again suggest that damage to contents in 2002 should be higher than in 2013.

Second Hypothesis: "More precautionary measures for contents were taken by households in 2013 or/and more households took at least one precautionary measure for contents"

Recalling the previous analysis of precautionary measures, the number of measures taken directed to reduce and prevent damages to content in both samples range around 0 and 3. In regard to the percentage of households that took precautionary measures that could reduce or prevent damage to contents, before the 2002 flood event, this value was of 21%. In contrast, 41% of the households in the sample of the 2013 flood took at least one precautionary measure directed to damage to contents. This evidence would again suggest that damage to contents in 2002 should be higher than in 2013.

Third Hypothesis: "More emergency measures for contents were taken by households in 2013 or/and more households took at least one emergency measure for contents"

In regard to the percentage of households that took emergency measures that could reduce or prevent damage to contents, during the 2002 flood event, this value was of 79%. In contrast, 93% of the households in the sample of the 2013 flood took at least one emergency measure directed to damage to contents. Concerning the number of emergency measures aiming to reduce and prevent damage to contents, statistics are the same for both samples (Table 6).

Table 6 *Number of emergency measures taken for reducing damage to contents for 2002 and 2013 floods*

	Number of emergency measures: content + hazard						
	Mean	**Median**	**Mode**	**Min**	**Max**	**25 percentile**	**75 percentile**
Flood 2002	2	2	3	0	4	1	3
Flood 2013	2	2	3	0	4	1	3

Fourth Hypothesis: Bias in answers in 2002 and 2013 with respect to damaged items

The questionnaires for the 2002 and 2013 floods had some differences. In particular, with respect to the questions on damaged contents, interviewees were asked if they suffered damages to the items of a predefined list. However, this list is different in both events, which could influence the number and kind of items that people considered as "contents". The list of items in 2013 includes much more elements with respect to 2002, which could explain why damages to contents in 2013 are of similar magnitude with respect to 2002 (Table 7).

Table 7 Damage items categories for the 2002 and 2013 questionnaires

Damage items categories in 2002 questionnaire	Damage items categories in 2013 questionnaire
Washing machine	Washing machine, dryer
Dryer	Refrigerator/Freezer
Refrigerator	Cooker/Oven
Freezer	Dishwasher
Cooker/Oven	TV, stereo system, VCR
Dishwasher	Computer/ Laptop
TV, stereo system, VCR	Fitted kitchen
Computer / Laptop	Telephone
Fitted kitchen	Antiques and artefacts
Microwave	Living room, children 's room furniture
Telephone	Bedroom furniture
	Flooring
	Hobby accessories, tools, electrical appliances
	Bathroom equipment
	Sauna, solarium
	Small items such as clothing, jewellery etc.

Hypothesis 4a: "More items were considered and reported as damaged contents in 2013 with respect to 2012"

Statistics on the number of items declared as damage to contents by household report a similar situation for the 2002 and 2013 samples (Table 8). Values for the number of reported items by household are slightly higher for the 2002 flood event.

Table 8 Number of damaged items (contents) reported by household for the 2002 and 2013 floods

	Number of damaged items (contents)						
	Mean	**Median**	**Mode**	**Min**	**Max**	**25 percentile**	**75 percentile**
Flood 2002	6	6	13	0	13	2	10
Flood 2013	5	4	2	0	14	2	7

Hypothesis 4b: "More expensive items were reported as damaged contents in 2013 with respect to 2012"

The list of items of 2013 includes some more expensive ones such as the sauna and antiques. Furthermore, there was an open answer for both 2002 and 2013 were interviewees could report an item that was not mentioned on the list but that was damaged and involved a considerable cost. Taking into account these aspects, the analysis showed that there were no "expensive" item categories reported in 2013.

Fifth Hypothesis: "Damage estimation to contents was done in a different way in 2002 and 2013"

Damage to contents is expressed in monetary values and used directly as it is to compare the impacts of the 2002 and 2013 flood events. However, this monetary value could represent different things. Damages can be expressed as costs of replacement or repair, depending on whether the item was replaced or repaired, due to the degree of damage of the item, type of item, the possibility of repair, cost of repair vs. replacement, etc. Furthermore, the estimate of these costs can vary depending on whether the item was already replaced/repaired, so the effective cost is known or if it is an estimate for future repair/replacement. At the same time, this estimation can be different if done by an expert or by the affected citizen. Unfortunately, this information is only available for the 2013 questionnaire, where a question was added regarding the type of estimation of damages to contents. Possible answers include: "invoice/receipt", "compensation/insurance expert opinion", "own estimate". Results show for 2013 that in half of the cases the estimation was done by an expert, while 29% of the residents estimated the damages themselves (Figure 39). This could have influenced the number of damages reported. However, without the 2002 data, it is difficult to conclude.

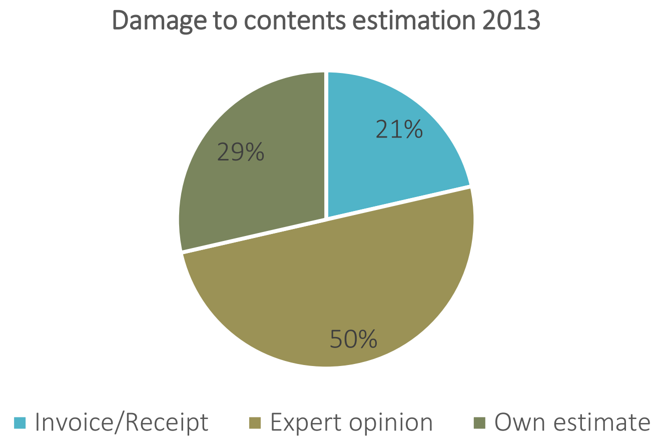

Figure 39 *Damage to contents estimation for the 2013 flood event*

The previous analysis ruled out all the generated hypothesis. Consequently, it indicates that flood duration could be a determining parameter in damages to contents, alongside water depth.

Response

In 2002, no timely flood warning was received in Grimma (Schanze et al., 2008). Data from the interviews at the household level (from University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung) show that the mean warning time that the residents had during the 2013 flood event was more than 4 times the one from the 2002 flood event (Figure 40). Other statistics such as the median and the mode also support this difference (Table 9).

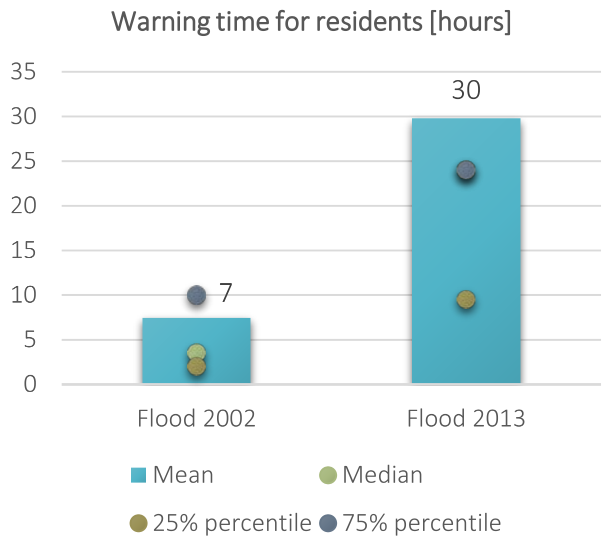

Figure 40 Warning time for residents within the samples [hours]

Table 9 Warning time statistics [hours] for the 2002 and 2013 flood event

	Warning time [hours]				
	Mean	**Median**	**Mode**	**Min**	**Max**
Flood 2002	7	4	2	1	24
Flood 2013	30	24	24	2	168

The analysis of the data at the household level (Figure 41) shows that in 2002, 45% of the households of the sample did not receive any kind of flood warning. Moreover, only 45% was warned by official sources. Instead, in 2013 (Figure 42) only 17% of the households in the sample did not receive any flood warning, while 78% received official warnings.

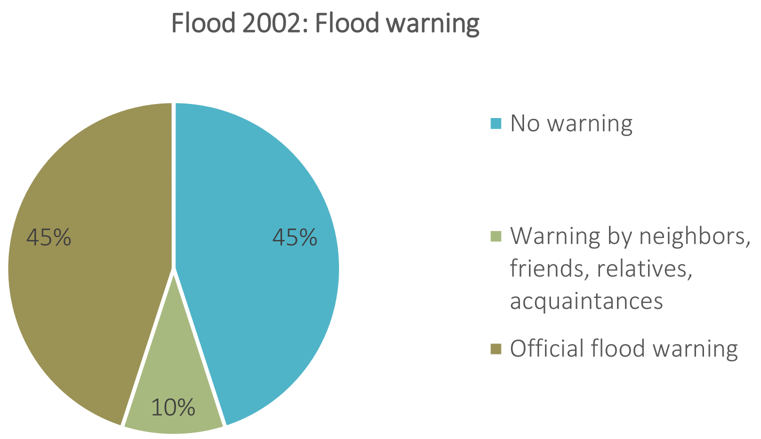

Figure 41 Flood warning distribution in households' data in the 2002 flood

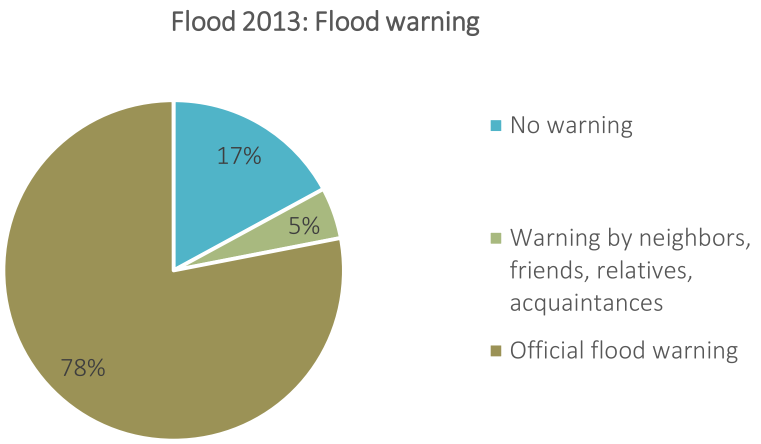

Figure 42 Flood warning distribution in households' data in the 2013 flood

Another variable that was analysed was the time spent on executing emergency measures during both of the floods. All the statistics show that the time spent on emergency measures during the 2013 flood event was much more than in 2002 (Figure 43, Figure 52 and Table 10).

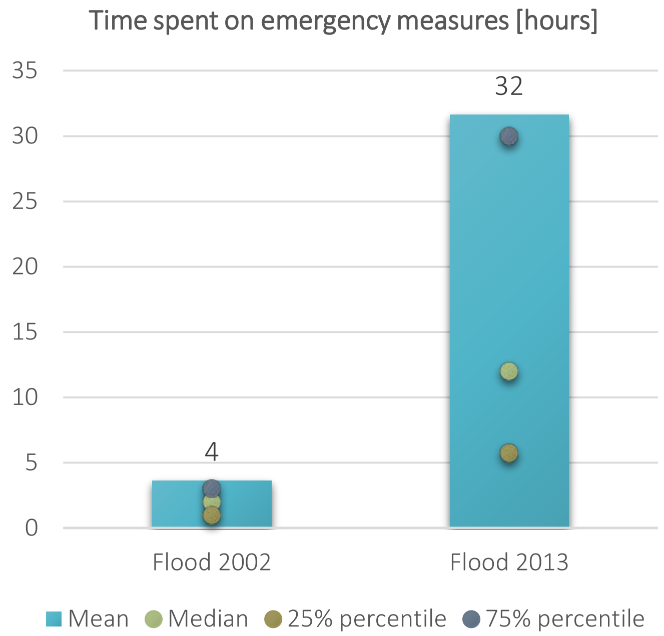

Figure 43 Time spent on emergency measures during the flood events [hours]

Table 10 Time spent on emergency measures statistics [hours] during the flood events

	Time spent on emergency measures [hours]				
	Mean	**Median**	**Mode**	**Min**	**Max**
Flood 2002	4	2	2	1	12
Flood 2013	32	12	12	2	192

Figure 44 shows the percentage of households within the samples that took at least one emergency measure during the 2002 flood and the 2013 flood events, respectively.

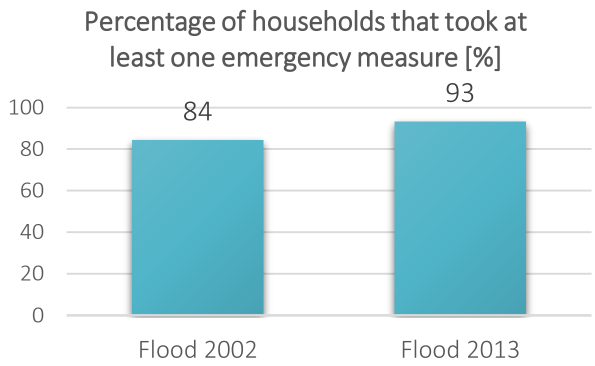

Figure 44 *Percentage of households that took at least one emergency measure during the 2002 and 2013 flood events*

The emergency measures mentioned in the interviews were of different types. These measures were classified in order to understand the influence that they may have had in the damage to the building and contents. Furthermore, given that the measures included in the interviews in 2002 and 2013 differ, this classification allows comparison. Consequently, emergency measures for preventing or reducing the damage to contents are classified as "content" measures, measures for reducing damage to the building are "building" measures and measures for reducing the hazard intensity are termed "hazard" measures (Table 11 and Table 12).

Table 11 *Emergency measures classification for the 2002 flood event*

Measure type	Emergency Measures (2002)
CONTENT	Moving documents and valuables to upper floors.
	Unplugging electric appliances.
	Furniture and movable objects raised or placed in safety.
BUILDING	Closing gas and electricity supplies for the whole building.
	Closing gas and electricity supplies in the apartment.
	Securing oil tanks or containers with other hazardous substances.
HAZARD	Protecting the building against the entrance of water.

Table 12 *Emergency measures classification for the 2013 flood event*

Measure type	Emergency Measures (2013)
CONTENT	Moving documents and valuables to upper floors.
	Furniture and movable objects raised or placed in safety.
BUILDING	Securing oil tanks or containers with other hazardous substances.
	Building deliberately flooded (for pressure relief).
	Closing gas and electricity supplies.
	Gas or electricity supply closed by the authorities.
HAZARD	Pumping water.
	Sealing doors, windows, drains and other openings.
	Use of sandbags or other means to avoid entrance of water.

The percentage of households within the sample that took at least one emergency measure concerning each category was calculated (Table 13). Furthermore, measures directed to reduce the intensity of the hazard are meant to reduce both the damages to the building and the contents. Consequently, they were considered also within both categories.

Table 13 Percentage of households within the sample that took at least one emergency measure during the flood events

	Percentage [%] of households that took at least one emergency measure for				
	Content	**Building**	**Hazard**	**Content+Hazard**	**Building+Hazard**
Flood 2002	79	37	26	79	53
Flood 2013	93	90	48	93	93

Evacuation and Rescue

Concerning evacuation during the 2002 flood, 1000 people were evacuated from the town centre, while 150 people needed to be rescued (Grimma Municipality, 2017). In the night of August 12, 49 students were evacuated from the boarding school St. Augustin, next to the Mulde River in Grimma (Grimma Museum, 2002). Furthermore, 53 people sought shelter in the Frauenkirche church in the centre of Grimma and had to wait until the evening of June the 2nd to be rescued with boats (ibid.). Unfortunately, there was one death reported in Grimma because of the 2002 flood (Mr Berger, 2006).

Concerning evacuation during the 2013 flood, according to mayor Berger, all the citizens of Grimma old town were evacuated without problems, in an ordered and professional way (n-tv, 2013). Nevertheless, on June 1st, when the flood began, some residents had to be rescued (Bild, 2013), while around 170 people spent the night in a gym near the old town (Welt, 2013). The water started to recede but during the night and morning of June 2nd, the water level started to rise again, and it was decided to evacuate the old town (Bild, 2013). The police drove with loudspeaker cars in the streets that were not flooded yet, requiring everyone to leave their apartments as soon as possible (ibid.). By June 2nd, 1000 residents evacuated from the centre of Grimma and were accommodated in gyms and other shelters (Bild, 2013). Another newspaper, Welt, reported that on June the 2nd water in the city centre at the market was around 1.5 m depth and that evacuation of the old town continued while the water level was rising, with the aid of two boats and a helicopter. By that time, 2000 people were brought to safety (Welt, 2013).

Recovery and Reconstruction

The 2002 flood attracted great media attention. As early as August 14, the then Federal Chancellor Gerhard Schröder, together with the former Prime Minister of Saxony, Georg Milbradt, and numerous media representatives, visited the centre of Grimma to get a picture of the extent of the damage (Siedschlag, 2010). The floods of 2002 occurred 3 weeks before the forthcoming Bundestag (parliament) elections and many public funds were available for damage compensation. The Confederation and the Free State of Saxony paid very high compensation to the affected citizens of Grimma, while important donations were also made (13 million euros) (Siedschlag, 2010).

The situation in 2013 was quite different. From the very first days of the flood the Mayor, who was still Mr Berger, expressed his concern about the city's recovery. In June 3rd, 2013, the mayor asked for "everyone's help" and explained that people were devastated after this second flood in almost 10 years (n-tv.de, 2013). He was sceptical on the help they would receive, both external and internal. A bank account was open for donations, as early as June 3rd (n-tv, 2013). Ten days later, in June the 14th, mayor Berger said he wanted help for reconstruction and stated that affected businesses did not need loans but grants that would not need repayment (LVZ, 2013). Many were still paying loans after the 2002 flood and many others would not be able to afford a loan even with a small interest rate (LVZ, 2013). This difference in financial aid availability is also reflected in the data collected at a household level (Figure 45).

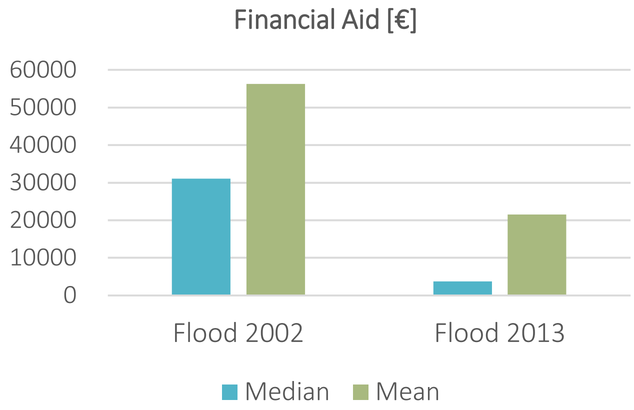

Figure 45 *Financial Aid received by household within the samples after the 2002 and 2013 floods [€]*

This difference is also present when considering financial aid as a ratio to the total damage (Table 14).

Table 14 *Financial aid (corrected for inflation to 2013) for households in the sample of the 2002 and 2013 floods.*

	Financial Aid	
	Median [€]	**Ratio to the total damage**
Flood 2002	31,096	0.46
Flood 2013	3,750	0.24

Reconstruction started relatively quickly after the 2002 flood and had been completed by the year 2004, reaching an improved condition with respect to the pre-flood state (Meyer et al., 2011). Nevertheless, it is not clear whether this improvement was only aesthetical or also comprised a vulnerability reduction with respect to pre-event conditions. In an interview in 2005, Mrs Guhlemann, Director of the Civil Engineering Office of Grimma, stated that an effort had been made to persuade residents to rebuild their households using flood-proof materials (Flood-ERA Project, 2008). Nonetheless, whether they had succeeded was unknown to her.

In regard to the 2013 flood recovery, during the first 5 days after the flood electricity, gas and water provision were reinstated, and the city was cleaned, with the disposal of 35 000 cubic meters of waste (LVZ, 2013). Data on reconstruction time is missing. However, fieldwork in June 2017 showed that almost all the buildings were in perfect conditions and no signs of the flood could be seen, except for some remembrances set by owners.

Population dynamics

The objective of this section is to understand if there were changes in the population before and after each flood event. On the one hand, these changes could be a consequence of the impacts of the flood (both positive and negative) or a cause that could explain some of the flood impacts (e.g. in terms of population vulnerability, recovery capacity, etc.). On the other hand, changes in population structure and migration could be due to other non-flood related factors.

The first element to study was migration, before, during and after both flood events. Figure 46 shows the population inflows and outflows for different years for both the municipality of Grimma and Grimma centre, with arrows indicating the occurrence of the floods. Data on the whole Grimma municipality are presented to control if trends in the city centre are different with respect to the rest of the area.

It is possible to see that population inflows (normalized with respect to 1997) in the city centre after 2002 were always greater than in total Grimma, with a positive trend. Furthermore, in 2013 and 2014 there is a drop in inflow values in the inner city, while this trend stayed positive in the larger municipality. Population outflows in the city of Grimma during the three years after 2002 were always lower than in 1997, as well as with respect to the whole municipality. After 2006, this trend in the inner city reversed and outflows started behaving as in total Grimma. In 2013 there is a peak in population outflows, the highest value since 1997, and then in 2014 again a drop to previous levels.

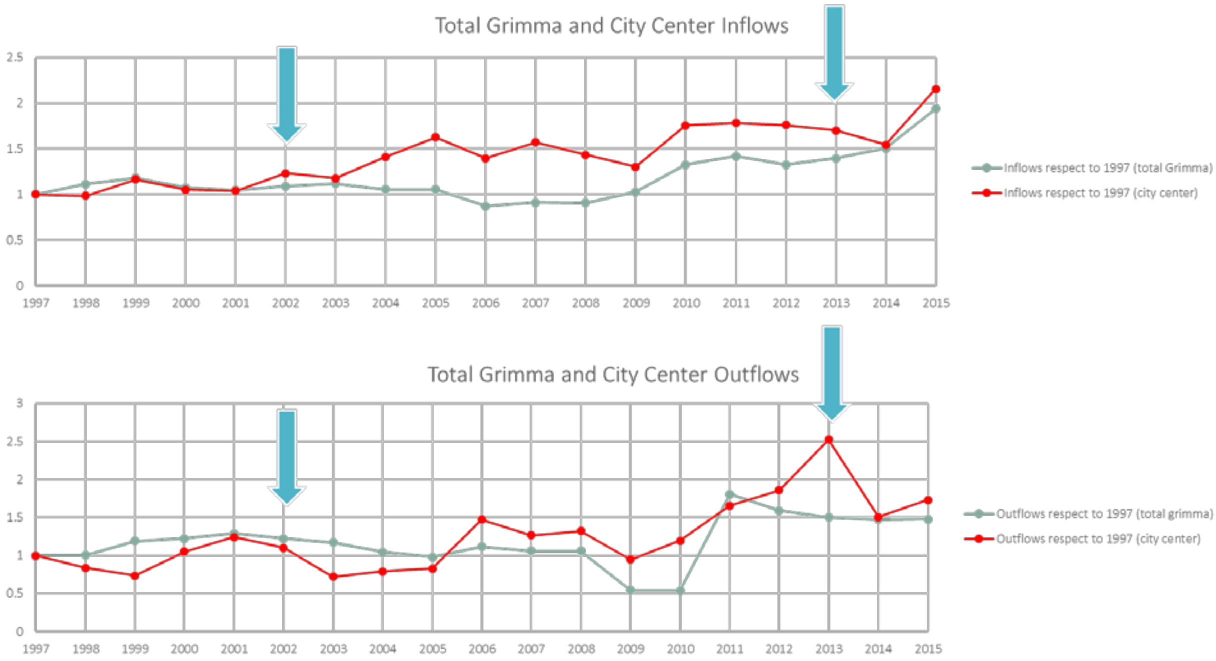

Figure 46 *Total Grimma and city centre population inflows and outflows (elaborated from data: Years 1997-2008, Daniela Siedschlag (2010) and Years 2008-2015 from Grimma municipal data).*

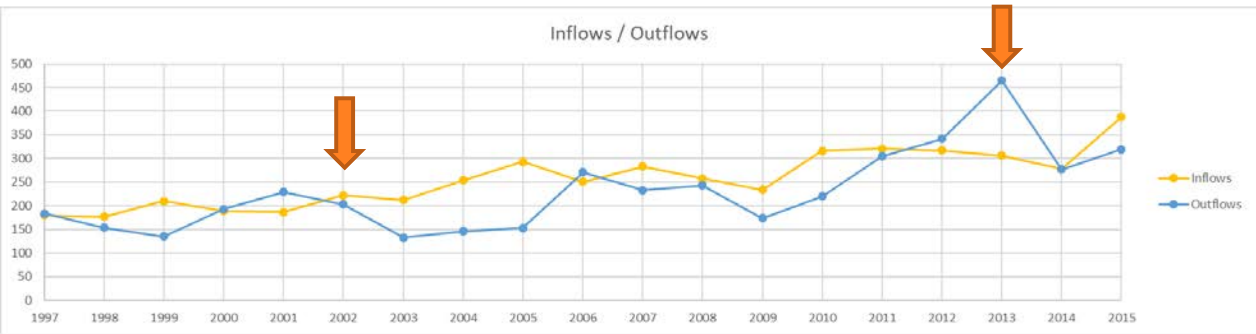

Figure 47 Grimma city centre population inflows and outflows (elaborated from data: Years 1997-2008, Daniela Siedschlag (2010) and Years 2008-2015 from Grimma municipal data).

The difference between inflows and outflows (sse Figure 47 and Figure 48) shows a positive balance from the years 2002-2006 and 2006-2011. Instead, from 2012 outflows begin to slowly overcome the number of inflows, reaching a peak in 2013.

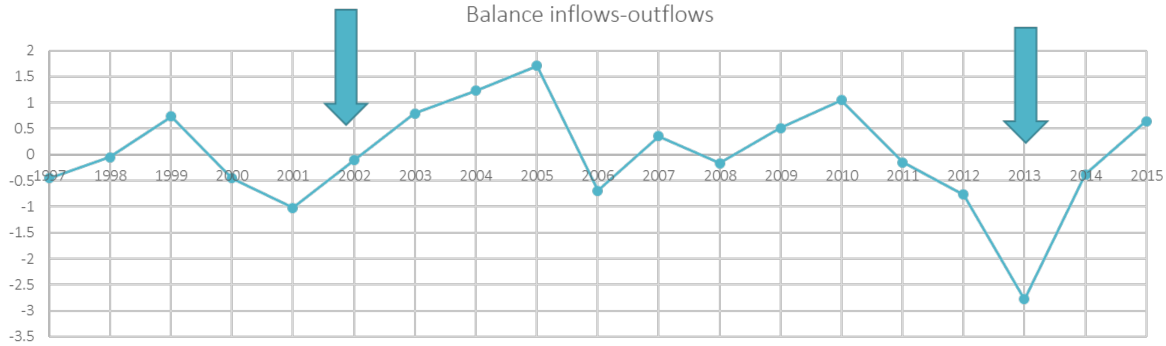

Figure 48 Normalized balance of population inflows-outflows in Grimma centre (elaborated from data: Years 1997-2008, Daniela Siedschlag (2010) and Years 2008-2015 from Grimma municipal data).

Age structure was also investigated, before and after the 2002 and 2013 floods. Results show that age structure in Grimma centre remained almost constant from 2001 to 2015 (Figure 49).

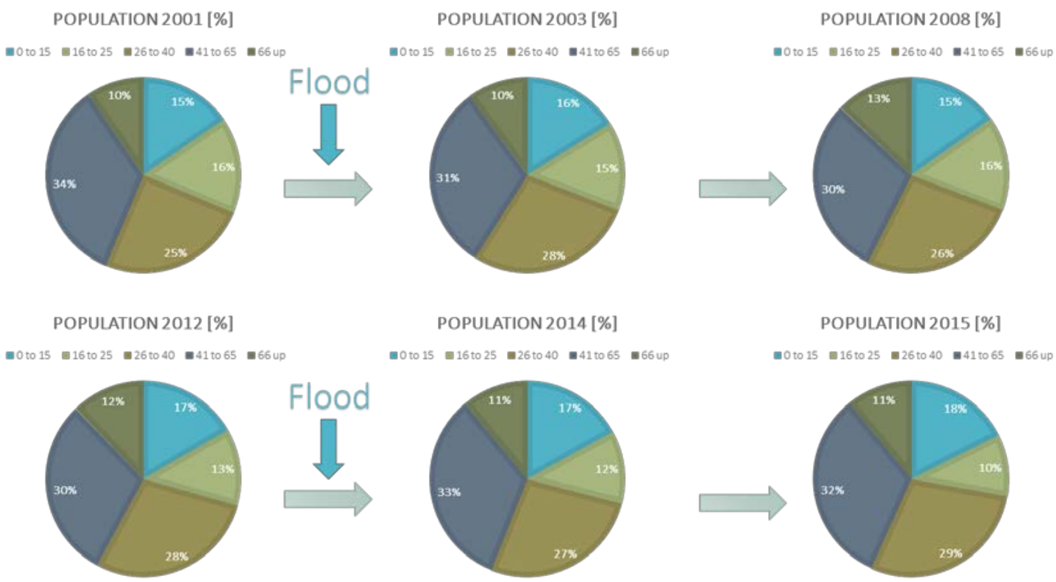

Figure 49 Age structure in Grimma inner-city in different years

SECTION IV: KEY INSIGHTS

Exposure and Vulnerability

Concerning the new police headquarters, Mayor Berger said in an interview that "the risk was the same as in other parts of the city" and that significant measures were being taken to protect it from flooding. However, in fact, flood risk is not same as in the rest of the city centre because it depends not only on the hazard, which could be similar but also on the exposure and vulnerability of the assets. The police have an important role in case of flood events, as the mayor recognised because they are the first ones to intervene. Thus, if the police station is flooded or isolated, it cannot execute its functions. Indeed, in 2013 the police headquarters were flooded and accessing roads were blocked, even if structural measures were taken to protect it because the floodwall was not finished. Repercussions of the flooding and isolation of the police station are unknown. Apart from physical and monetary damages, it would be interesting to know how this affected police officers' functions. Structural defences at the police headquarters provide protection up to a certain water level (i.e. 1.5m, according to a flood of 100 years of return period). This means that for flood scenarios of more than 100 years of return period, police headquarters will be affected.

Prospective and Corrective risk reduction: The new floodwall

The floodwall was not finished by the time of the second flood due to a lack of consensus with Grimma's citizens. This required the development of a new project that delayed the initiation of the construction works. A different approach to this issue from the time the project was under development might have avoided protests and accelerated the beginning of the works. If the floodwall had been finished by 2013, probably most of the damages would have been prevented. Mayor Berger stated that with a finished floodwall, water would have stayed out 100 per cent (Spiegel, 2013). However, the protection structure was designed for a flood of 100 years return period, while the flood in 2013 was of around 172 years. Consequently, some areas in Grimma could have been flooded anyway.

Flood Damages

The analysis of damages to buildings in the 2002 and 2013 floods shows that building damages were driven by hazard intensity (water depth), early warning time, measures taken during response and prevention measures, as expected. Monetary damages to buildings in 2002 were in mean 25% higher than in 2013, in line with the important difference between water depths in both events. Warning time, time spent on emergency measures and the percentage of households that took both emergency and prevention measures were also higher in 2013.

Concerning damages to household contents, water depth played a less important role. The analysis of different hypotheses indicated that flood duration could be the most determining parameter in damages to contents in Grimma's floods.

Response

In 2002, no timely flood warning was received in Grimma (Schanze et al., 2008). Furthermore, the important difference in warning times in 2002 and 2013 would indicate that the new local early warning system was effective. The time spent on emergency measures in 2013 was also much more important than in 2002. Nevertheless, even if warning time in 2013 was more than 4 times the one of 2002, the number of emergency measures that were taken was very similar and only slightly bigger in 2013. Moreover, the percentage of households within the samples that took at least one emergency measure during the 2002 flood was 84% and 93% in 2013. This difference is not very significant, but these numbers refer only to the households within the sample.

Concerning evacuation, it is still not very clear how effective evacuation was in 2013. According to Grimma's mayor, all the citizens of Grimma inner city were evacuated without problems (n-tv, 2013). Nonetheless, some citizens needed to be rescued after the first phase of the flood. In contrast, during the second phase of the flood, police cars were still circulating the streets while the water level was increasing (Bild, 2013). Moreover, Saxony's Minister of Interior on June the 2nd appealed to citizen's reason regarding evacuation (Welt, 2013). He said that he understood that people were afraid about their property, but that it was not possible that authorities had to force them to evacuate and that if not, they would need rescue. It is not clear whether there were problems with people's willingness to evacuate also in Grimma.

Recovery

Recovery conditions in both flood events were different because the 2002 flood occurred weeks before parliament elections. This is reflected in the availability of funds at a household level. The compensation received by households in 2013 corresponds to only 24 % of the total damage they suffer, while in 2002 this was twice the value, with 46% received. The impacts that this lack of funds had on recovery and reconstruction are not very clear. Data on recovery time for the 2013 flood is not available. Even if fieldwork showed that almost every building was renovated by 2017, it is not known when works were finished.

Another important aspect related to the funds available for compensating damages concern affected businesses. Mayor Berger said that affected businesses were still paying loans after the 2002 flood and many others would not be able to afford a loan even with a small interest rate (LVZ, 2013). It could be the case that some businesses, struggling after the flood, had to close. Unfortunately, there is no data to corroborate this aspect.

Population dynamics

The positive balance of population inflows-outflows and the increase of inflows after 2002 would corroborate the fact that the city centre became more attractive after refurbishment, therefore attracting a new population. Another important factor was the availability of financial aid and a positive public image, in both national and international media. The 2013 flood had the opposite effect, causing emigration from the city centre due to a lack of financial aid, a negative attitude from the population and mayor, and a negative public image in the media.

Concerning age structure, given that the changes in time of the population composition were negligible, it is not possible from the comparison of both events to discern if this factor had any role on the impacts of the floods. However, it is possible to say that the flood did not affect age composition (e.g. refurbishment attracting younger population, age groups that might have left due to the floods, etc.).

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