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Forensic Investigation of Post-Flood Damage Data to Support Spatial Planning

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ABSTRACT

This Thesis explores the use of Disaster Forensic Investigation to support the development of spatial plans in flood-prone areas, to prevent and reduce flood risk. The knowledge from forensic investigation can be added to the knowledge base used at different spatial planning levels. Disaster Forensic Investigation is a very recent tool (and one of the usages of disaster damage data) to extract lessons learned after a disaster, originally designed to inform Disaster Risk Reduction (DRR) policy-making and practice. Existing forensic investigation methods fail at considering the key role of spatial planning in the generation of exposure and vulnerability of cities and territories.

A new Disaster Forensic Investigation method was developed in this research that is a comprehensive analysis of the disaster that makes use of post-flood damage data. It aims at (i) understanding the causes of the disaster and its damages, and (ii) identifying the role of spatial planning in shaping disaster risk (i.e. whether spatial planning is a relevant risk driver or whether it contributed to risk prevention or reduction). This method was applied in the analysis of two case studies: The 2002 and 2013 floods in the town of Grimma, in Saxony, Germany and the 2012 flood in the Umbria Region, Italy, in Ponticelli, in Città della Pieve and Orvieto Scalo and Ciconia, in Orvieto.

Findings of this research reveal that the new Disaster Forensic Investigation method is an effective tool for mainstreaming flood risk prevention and reduction in spatial planning at different levels. The Umbria and Grimma case studies showed that the lessons learned from Disaster Forensic Investigation can support the definition of actions for flood risk prevention and reduction at both regional and local planning levels. Flood risk management can be mainstreamed in spatial planning through (i) the introduction of DRR measures to reduce and prevent risk in planning instruments, and (ii) spatial plans that act as instruments for risk prevention and reduction. The case studies also revealed that the lessons learned from Disaster Forensic Investigation can be integrated into the knowledge base of existing planning instruments at different levels (in Italy, France and Germany) and support the definition of actions towards flood risk prevention and reduction for both the existent and the future built environment. In addition, results of this research include the link between Disaster Forensic Investigation and a new taxonomy of flood risk management measures that supports the selection of actions to effectively mainstream flood risk prevention and reduction in spatial planning at different levels, applicable to different contexts.

Keywords: Disaster Forensic Investigation, Disaster Risk Reduction and Spatial Planning, Post-flood damage data, Flood risk prevention.

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1 INTRODUCTION

1.1 PROBLEM STATEMENT: POOR SPATIAL PLANNING AS A "DISASTER RISK DRIVER"

Floods are "acts of God," but flood losses are largely acts of man. (White, 1945: 2)

This quote was written more than 70 years ago in Gilbert White's PhD Thesis and is still relevant today. Nonetheless, floods are generally referred to as "natural" disasters, a term that neglects and overlooks the human influence in their creation. Floods are a global phenomenon that causes widespread devastation, economic damages and loss of human lives. In recent years, both the number of people affected by floods and flood damages have been rising significantly. Between 1998 and 2017, floods were the most frequent type of disaster, affecting more than 2 billion people and causing US$ 656 billion in damages (Wallemacq et al., 2018). In particular, the increase in economic losses is entirely explained by changes in socioeconomic factors such as population growth, wealth and increasing development in hazardous areas (Barredo, 2009, IPCC, 2012, Mohleji and Pielke, 2014, GFDRR, 2016, Paprotny et al., 2018). Flood events manifest themselves as disasters when combined with the exposure and vulnerability of human settlements and communities.

Urbanisation in hazardous areas results in larger concentrations of exposure, a dynamic factor that increases as the population grows and as improved socioeconomic conditions raise the value of assets (GFDRR, 2016). In Italy, almost 17 million people (28% population) are exposed to floods (ISPRA, 2016), where approximately 23% of the territory is under flood risk (Trigila et al., 2015). Expansion of urban populations in hazardous areas increases exposure through both increased density and outward expansion. This is key when considering that more than half of the world's population currently lives in urban areas and that this ratio is expected to grow in the next decades. Besides new development, also choices on redevelopment or regeneration of existing areas, as well as of preservation of current built assets have an impact on flood risk.

In addition, cities are at great risk also from their own multiple vulnerabilities (Moor, 2001). Settlements are becoming more complex and more dependable on extended networks and infrastructure (e.g. water, energy, transportation and telecommunications). Dysfunction of any of these lifelines can cause cascade effects that can transcend the disaster area and even affect several nations. Vulnerability evolves due to decisions made during the development process (GFDRR, 2016). Hence, disasters and the vulnerability that underlies them are not inevitable (Pelling, 2006). The number of future disaster damages and impacts depend on how we design, redesign and build human settlements today.

Efforts in Disaster Risk Reduction (DRR), i.e. the concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters (UNISDR, 2017c), have been principally directed towards protecting development. This encapsulates a fundamental contradiction: it aims to protect the same development paradigm that generates risk in the first place (UNISDR, 2015a). If investments are made to protect the existing built environment while building without addressing underlying risk drivers, disaster risk will continue to be generated faster than it can be reduced (ibid.). It is necessary then to prevent the generation of disaster risk by acting on the causes of disasters and their impacts.

In this context, poor spatial planning and unplanned urbanisation are disaster risk drivers (UNISDR, 2009) that increase both exposure and vulnerability. The term “disaster risk driver”, coined by the UNISDR (United Nations Office for Disaster Risk Reduction), refers to the “processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity” (UNISDR, 2017a). As Wamsler (2008) shows, one of the main causes of disasters is the way that the built environment is developed with its associated planning practices, by creating increased vulnerabilities and exposure to existing hazards and sometimes even by intensifying hazards or creating new ones. Lessons Learnt from Natural Disasters (NEDIES, European project) also show that the lack of consideration of disaster risk in urban planning in Europe is a fundamental cause of damage, especially for floods (Esteban et al., 2011). Similarly, in Italy, current hydrogeological risk conditions are linked not only to the features of the territory but mainly to the strong increase in urbanisation in hazardous areas, in absence of proper spatial planning (Trigila et al., 2015).

Unplanned urbanisation in hazardous areas is generally motivated by rapid urbanisation, particularly in developing countries due to an increase of population and rural-urban migration. On the other hand, poor spatial planning is often the result of the lack of integration of disaster risk considerations in the planning process.

Spatial planning is key in shaping disaster risk by steering development and configuring the built environment. Besides the negative role of spatial planning in creating disaster risk, it can also have a positive and proactive part in risk prevention and reduction. Spatial planning has a powerful capacity for reducing (Wamsler, 2008) and preventing disaster risk. In fact, the positive role that spatial planning has in preventing flood damages has been recognised for decades. For example, as Burby (1998) mentions, as early as 1950 U.S.A president Truman acknowledged the shortcomings of flood mitigation through structural protection and recommended a new "land use approach". It was based on what Burby (1998) calls "location and design land use measures", by keeping development away from flood-prone areas or by reducing the vulnerability of the built environment when development is economically justified. Likewise, since the 1990s several scholars have been stressing the importance of land use planning for risk prevention and reduction (Galderisi & Profice, 2012).

Recent policies, both in DRR and urban planning, have also acknowledged the key function that spatial planning has in shaping disaster risk. In order to prevent and reduce disaster risk, these policies call for the integration of DRR knowledge, strategies and measures in spatial planning practices at all levels. The Sendai Framework for Disaster Risk Reduction 2015-2030 introduced a paradigm shift from disaster management to integrated and anticipatory disaster risk management, which recognises that the only way to manage disaster risk is to manage the processes that create it (UNISDR, 2015b). Sendai considers the mainstreaming of disaster risk assessments into urban planning to both prevent risk generation and to reduce existing risk. The New Urban Agenda, adopted in 2016 at Habitat III, committed to moving from a reactive to a proactive approach towards disaster risk. Spatial planning is suggested as a means to prevent risk, strengthen resilience and reduce vulnerabilities of cities and human settlements. At the European level, the Directive 2007/60/EC ("Floods Directive"), formally incorporates spatial planning in the management process (Hartmann et al., 2013, 2016) and specifically declares spatial planning as a relevant aspect in flood risk management. A detailed analysis is presented in Chapter 2.

Even if the policies call for the integration of DRR knowledge in spatial planning, the review on the DRR knowledge (on floods) currently used in spatial planning at different levels (Chapter 2) shows that it is either non-existent or very poor. The analysis of the present state of regional plans of the twenty Italian regions shows that only flood hazard information is used to inform planning decisions. In contrast, knowledge on flood risk and exposure are hardly considered and vulnerability is always missing. A similar situation regards the DRR knowledge at the local planning level in Italy and other EU countries. The DRR knowledge currently used is insufficient for supporting spatial planning for disaster risk prevention and reduction at all spatial levels (regional and local).

1.2 HYPOTHESIS

The hypothesis of this research is that Disaster Forensic Investigation can support the development of effective spatial plans at different levels in flood-prone areas, to prevent and reduce flood risk.

1.3 DISASTER FORENSIC INVESTIGATION AS THE MAIN TOPIC

This research started in association to the European project IDEA (Improving Damage assessments to Enhance cost-benefit Analyses), which aimed at developing enhanced methods and tools for the collection, analysis and use of disaster damage data for multiple purposes. Amongst these data usages and analysis is Disaster Forensic Investigation to acquire lessons learned after a disaster. Forensic investigation applied to the study of disasters is very recent and used only to inform DRR policy-making and practice. It has never been used to support spatial planning practices of any kind. In fact, this innovative aspect of the research emerged during the IDEA project. In this context, I selected to explore Disaster Forensic Investigation to understand its possible use in supporting spatial planning practices in flood-prone areas. Another associated aspect is the planning level and instruments in which to introduce the DRR knowledge from Disaster Forensic Investigation.

The literature review on existing methods for disaster forensic investigation (chapter 3) reveals that the process that needs to be followed to perform an analysis of this kind is hardly clear. Another innovation of this research is the development of a new Disaster Forensic Investigation method for a comprehensive analysis of disasters. The aim of this new method is twofold: (i) understanding the causes of the disaster and its damages, and (ii) identifying the role of spatial planning in shaping disaster risk (i.e. whether spatial planning is a relevant disaster risk driver or whether spatial planning contributed to disaster risk prevention or reduction).

1.4 POST-FLOOD DAMAGE DATA AND DISASTER DAMAGE DATA COLLECTION IN POLICIES AND PRACTICE

Forensic investigation is one of the many usages of disaster damage data, alongside loss accounting, risk modelling and compensation. A general interest arose in the last years to define and regulate disaster damage data collection processes in order to properly support policy makers and decision makers for DRR. Several frameworks and policies at different levels call for the systematic assessment and record of disaster damages for multiple purposes. There has been growing reflection and awareness on how such data are essential and useful to support different DRR policies (see JRC expert working group, De Groeve et al., 2013, 2014, 2015 and Marín Ferrer et al. 2018; DATA Project by IRDR, 2014 and 2015).

In this work, I consider disaster damage data related to a flood event and refer to it as "post-flood damage" data. The prefix "post" indicates the time of the data collection and the type of data. This means that the data under consideration are collected after the flood event, i.e. after the emergency phase, when the water recedes. They all correspond to damage assessments done at the end of the emergency and/or in the recovery period. The term "damage" in this context refers to all the impacts of floods on different exposed sectors: residential buildings, networks and infrastructure, public facilities, economic assets, environmental goods, cultural heritage and the population (Hubert et al., 1999, Merz et al., 2010 and Meyer et al., 2013).

On the one hand, international as well as European DRR policies explicitly require disaster damage data collection. On the other hand, in the last years, we have assisted to wide-ranging post-disaster damage assessments carried out by academia, the private sector, governments or international organisations all over the world (OECD, 2014). The JRC (Joint Research Centre) report, titled "Current status and best practices for disaster loss data recording in EU Member States" (2013) shows that the process of damage data collection consists of 1) the damage data collection as such (to assess and measure the damage), and 2) the damage data recording in an organized way. Both processes involve several actors, which do not necessarily coincide. Actors involved in the collection and recording of damage data include public structures (e.g. Civil Protection organizations, governmental entities and public administration agencies), private/public organizations (e.g. insurance companies, research institutions and Universities) and private companies, such as utility (water provision, electricity, etc.), telecom and transportation companies. These actors collect and/or record data of different characteristics and for very different purposes. This fact challenges the usability of the disaster damage data for other purposes than the one for which it was originally collected. For example, damage data collected for compensation purposes may present shortcomings when used for risk modelling or forensic investigation.

1.5 SCOPE

This research project focuses on floods as a particular type of disaster, on post-flood damage data as a type of disaster damage data and on Disaster Forensic Investigation as a tool and method for data analysis. The Thesis includes a review of recent Disaster Risk Reduction (DRR) and Urban Planning policies, alongside the state of the art of Flood Risk Management in Italian Regional Plans and in planning at the local level in selected EU countries (Italy, Germany and France). Furthermore, it comprises a literature review on existing approaches for forensic investigation in DRR. The review is completed with an analysis of disaster damage data collection in policies and on current European practices.

The research project makes use of two main case studies of towns that suffered one or several flood events. The first case is the town of Grimma, in Saxony, Germany, that was affected by two floods, in 2002 and 2013. The second case study involves three localities in the Umbria Region (i.e. Ponticelli in Città della Pieve, and Orvieto Scalo and Ciconia in Orvieto), which were flooded in 2012.

1.6 SIGNIFICANCE OF THE RESEARCH FOR SELECTED AUDIENCES

This research project is directed mainly to spatial planners at different levels. However, the exploration of the disaster forensic investigation throughout the research project shows that there are other actors for which these results are useful. For instance, the literature review on forensic investigation methods and the application of the tool in the two case studies show that the results of this analysis are useful for all the actors involved in the management of disaster risk, including emergency management.

1.7 STRUCTURE OF THE THESIS

This Thesis is organised in four main parts: the introductory theoretical part, the methodological part, the empirical part and the concluding part. These four parts are structured in eight chapters.

Chapters 2 and 3 constitute the first part of the Thesis. Chapter 2 presents the state of the art of Spatial Planning and Disaster Risk Reduction (DRR) in policies and practice. It starts with the analysis of the main DRR and urban policies to understand the way in which they approach spatial planning to prevent and reduce disaster risk. It continues with the analysis of the information related to flood hazard, flood risk or flood risk management that is currently present in the knowledge base used in spatial planning at different levels. This study includes the state of the art in Italian Regional Planning and at the Local Planning level in selected EU countries (Italy, France and Germany).

Chapter 3 presents the literature review on existing methods for Disaster Forensic Investigation, their purpose and use in DRR and the data that they require. Given that disaster damage data are essential to conducting a forensic investigation, this review is completed with the state of the art on disaster damage data collection in international policies and in practice in the European context.

Chapter 4 forms the methodological part. It is an important chapter with the description of the process designed for conducting this study and the development of a New Method for Disaster Forensic Investigation. This chapter ends with the selection of the case studies, the description of the case studies data collection and analysis.

Chapters 5 and 6 constitute the empirical part of the Thesis. Chapter 5 analyses the first case study: the town of Grimma, Saxony, Germany in the 2002 and 2013 floods. Chapter 6 analyses the second case study: three towns in the Umbria Region, Italy in the 2012 flood. The first town is Ponticelli in the municipality of Città della Pieve. The other two are Orvieto Scalo and Ciconia in the municipality of Orvieto. The new Disaster Forensic Investigation method is applied in both case studies in order to extract lessons learned after the floods.

Chapter 7 and 8 are the concluding part of the Thesis. Chapter 7 starts with the presentation of the "Revised" New Method for Disaster Forensic Investigation and the definition of the data categories required for its application. It discusses the lessons learned from Disaster Forensic Investigation and their use in spatial planning. The Grimma and Umbria case studies are analysed in terms of their lessons learned and their potential introduction in existing planning instruments in Italy, France and Germany. Next, Disaster Forensic Investigation is linked to actions and measures to mainstream flood risk prevention and reduction in spatial planning at different levels. Chapter 7 finishes with a reflection on possible organisations that could be in charge of performing the Disaster Forensic Investigation. Last, Chapter 8 presents the conclusions of the research.

2 SPATIAL PLANNING AND DRR IN POLICIES AND PRACTICE

This chapter presents first an analysis of the main DRR and urban policies to understand the way in which they recommend approaching spatial planning to prevent and reduce disaster risk. Then, in order to understand if policy recommendations are implemented in practice, the state of the art on the knowledge on floods used in spatial planning is analysed. The analysis aims at identifying the information related to flood hazard, flood risk or flood risk management that is currently present in the knowledge base used in spatial planning at different levels. This analysis starts with the European Flood Risk Management Plans. It continues with the state of the art in Italian Regional Planning. Last, the Local Planning level is studied in selected EU countries (Italy, France and Germany).

2.1 SPATIAL PLANNING AND DRR IN POLICIES

The most relevant DRR and urban policies are analysed next in order to understand the way in which each of them approaches spatial planning to reduce and prevent disaster risk. The focus of this thesis is specifically on floods. Therefore, flood risk management policy will be explored as a particular case of DRR policy.

2.1.1 Sendai Framework for DRR 2015-2030

The Sendai Framework introduced a clear shift in focus from disaster management to integrated and anticipatory disaster risk management; “disaster risk management is not to be considered a ‘sector’ in itself, but a practice to be applied across sectors” (UNISDR, 2015c: 4). This paradigm shift recognises that the only way to manage disaster risk is to manage the processes that create it (ibid.).

The Sendai Framework for Disaster Risk Reduction 2015-2030 is the successor agreement of the Hyogo Framework for Action and was adopted at the Third World Conference on Disaster Risk Reduction. The rationale behind the adoption of the Hyogo Framework for Action in 2005 ("Building the Resilience of Nations and Communities to Disasters") was the international acknowledgement that efforts to reduce disaster risks must be systematically integrated into policies, plans and programmes for sustainable development (United Nations, 2005). Even if efforts had been made since the adoption of the Hyogo Framework for Action and progress was achieved in reducing the loss of lives, disasters continue to undermine progress and efforts towards sustainable development.

The expected outcome of the Sendai Framework for the years 2015-2030 builds on the one defined for the Hyogo Framework (i.e. "the substantial reduction of disaster losses, in lives and in the social, economic and environmental assets of communities and countries", United Nations, 2005:3), but adds as a new element, that is the substantial reduction of disaster risk. This outcome will be achieved by pursuing the goal of preventing new and reducing existing disaster risk while strengthening resilience (UNISDR, 2015b).

The Sendai Framework proposes numerous actions for implementation, in pursuance of the expected outcome and goal. Many of these actions include spatial, urban and land-use planning aspects, both pre- and post-event, during reconstruction. For instance, the mainstreaming of disaster risk assessments into land-use and urban planning and the integration of disaster risk reduction into development measures to build back better. Land use planning is considered a measure by itself that can both prevent and reduce disaster risk in the medium and long-term. Other measures focus on relocation to areas outside the risk range of (i) public facilities and infrastructures, and of (ii) human settlements through the formulation of public policies.

2.1.2 New Urban Agenda

Heads of State and Government, Ministers and High Representatives committed in the New Urban Agenda to move from a reactive to a proactive approach towards disaster risk, by preventing risk, strengthening resilience and reducing vulnerabilities of cities and human settlements. Spatial planning is suggested as a means to achieve this, by adopting and implementing integrated policies, plans and approaches in line with the Sendai Framework and by mainstreaming data-informed disaster risk reduction and management at all levels.

The New Urban Agenda was adopted in 2016 at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), setting a new vision for cities and human settlements for the next 20 years. Disaster Risk Reduction is defined as a key element in achieving sustainable development. In fact, the new-shared vision includes cities and human settlements that "adopt and implement disaster risk reduction and management, reduce vulnerability, build resilience and responsiveness to natural and man-made hazards". Effective implementation for the New Urban Agenda foresees the integration of disaster risk reduction considerations and measures into urban and territorial planning processes.

Implementation of the New Urban Agenda is in its beginnings. Nations prepared reports in anticipation of Habitat III, explaining the changes taking place in their territories and the challenges for the New Urban Agenda. They also mention the activities they are pursuing in relation to different key areas and challenges. For example, in the Italian report the actions mentioned regarding flood risk are mainly basin planning, through both the PAI ("Piano di Assetto Idrogeologico" established by law in 1989) and the new Flood Risk Management plans, following the European Floods Directive (Directive 2007/60/EC), and Civil Protection activities. Concerning the integration of disaster risk reduction in urban planning, just seismic risk is considered through the integration of risk analysis in land management favoured by recent regional urban planning laws. A similar situation regards the German report, where the main activities towards flood risk management are crisis management, the implementation of the Floods Directive and the National Flood Protection Programme, established after the 2013 floods. This programme focuses on flood hazard mitigation measures (e.g. dyke shifts and retention areas). Spatial and land-use planning for flood protection and prevention is considered briefly in relation to climate change adaptation but focused only on the "flood" prevention and not on the "risk" (still hazard oriented).

2.1.3 The European Floods Directive

The European Directive 2007/60/EC ("Floods Directive") on the assessment and management of flood risks, requires the Member States to develop Flood Risk Management Plans, which represent a step towards the institutionalization of an ongoing paradigm shift in dealing with floods (Hartmann et al., 2016). For a long time, flood management focused exclusively on flood protection: It was the responsibility of hydraulic engineers to design physical measures that kept the water out (ibid.). In the last 20 years, the unique goal of controlling the flood "hazard" enlarged towards the management of flood "risks" (Klijn et al., 2008). Flood risk management takes the flood as such for granted and pursues damage prevention and mitigation, acting on the vulnerability of the flood prone area (ibid.).

The aim of the Floods Directive is to establish a framework for measures to reduce the risks of flood damages to human health, the environment, cultural heritage and economic activity. The Directive requires the consideration of different flood scenarios: Floods with high probability, with medium probability (for which structural protection measures are usually designed) and extreme event scenarios. During extreme flood scenarios, areas that are usually protected by defence measures like levees become flooded. This means that the line that used to separate wet from dry land does not exist anymore, and, thus, flood risk management becomes spatial since areas behind levees must be explicitly taken into account (Hartmann et al., 2013, 2016). The Directive formally incorporates spatial planning in the management process (ibid.), also by specifically declaring spatial planning as a relevant aspect of flood risk management.

Each European country transposed the Directive in their own legislative systems. For example, the Directive was transposed in Italy in the Legislative Decree 49/2010 and in Germany, enacted in German law in the Federal Water Act (WHG). Flood Risk Management Plans were developed in all member countries and for international basins (e.g. Elbe and Danube basins) by December 2015.

2.1.4 Conclusions on spatial planning and DRR in policies

The Sendai Framework, the New Urban Agenda and the Floods Directive make similar recommendations on how to approach Disaster Risk Reduction and spatial planning in order to prevent and reduce disaster risk. These approaches were classified into three main types (Table 1). The first is to mainstream DRR knowledge in spatial planning, for instance in the form of disaster risk assessments. The second regards the introduction of DRR measures in spatial planning. The last one is the use of spatial planning and land use planning as DRR measures by themselves.

Table 1 Approaches to DRR and spatial planning in main policies (source: author).

Policy	**Approaches to DRR and Spatial/Urban planning**	**Type**
Sendai Framework for DRR	Mainstreaming of disaster risk assessments into land-use and urban planning	DRR Knowledge in spatial planning
	Integration of disaster risk reduction into development measures	DRR measures in spatial planning
	Land use planning as a measure to prevent and reduce disaster risk	Land-use planning as DRR measure
New Urban Agenda	Integration of disaster risk reduction considerations and measures into urban and territorial planning processes	DRR measures in spatial planning
	Spatial planning as a means to prevent risk, strengthen resilience and reduce vulnerabilities of human settlements	Spatial planning as DRR measure
	Mainstreaming data-informed disaster risk reduction and management in spatial planning	DRR Knowledge in spatial planning
EU Floods Directive	Land use planning policies and/or regulation as measures to prevent flood risk	Land-use planning as DRR measure
	Flood risk management plans shall take into account relevant aspects such as spatial planning and land use planning	Spatial planning as DRR measure

2.2 EUROPEAN FLOOD RISK MANAGEMENT PLANS

The Floods Directive asks the Member States to develop Flood Risk Management Plans coordinated at the level of the river basin district (i.e. "the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters", Water Framework Directive, 2000). These plans shall be based on both flood hazard and risk maps and completed by December 2015. Both the maps and the plans must be reviewed and updated every six years.

The Directive asks the Member States to identify in each river basin district those areas for which they conclude that potential significant flood risks exist or might be considered likely to occur. Flood Risk Management Plans shall include measures for the management of flood risks that focus on the reduction of potential flood damages and, if appropriate, on the reduction of the likelihood of flooding. These measures should address prevention, protection and preparedness. In fact, measures are classified according to the stage of the flood risk management cycle on which they act.

Table 2 Classification of Flood Risk Management Measures according to the Floods Directive (source: EC, 2013).

Aspects of Flood Risk Management	**Objective**	**Type**	**Description**
Prevention	Preventing damage caused by floods.	Avoidance	Measures to prevent the location of new or additional receptors in flood-prone areas, such as land use planning policies or regulation.
		Removal or relocation	Measures to remove receptors from flood-prone areas, or to relocate receptors to areas of lower probability of flooding and/or of lower hazard.
		Reduction	Measures to adapt receptors to reduce the adverse consequences in the event of a flood, actions on buildings, public networks, etc.
		Other Prevention	Other measures to enhance flood risk prevention (may include, flood risk modelling and assessment, flood vulnerability assessment, maintenance programmes or policies, etc.).
Protection	Reducing the likelihood of floods in a specific location through structural and non-structural measures.	Natural Flood Management / Runoff and Catchment Management	Measures to reduce the flow into natural or artificial drainage systems, such as overland flow interceptors and/or storage, enhancement of infiltration, etc. and including in-channel, floodplain works and the reforestation of banks, that restore natural systems to help slow flow and store water.
		Water Flow Regulation	Measures involving physical interventions to regulate flows, such as the construction, modification or removal of water retaining structures (e.g., dams or other online storage areas or development of existing flow regulation rules), and which have a significant impact on the hydrological regime.
		Channel, Coastal and Floodplain Works	Measures involving physical interventions in freshwater channels, mountain streams, estuaries, coastal waters and flood-prone areas of land, such as the construction, modification or removal of structures or the alteration of channels, sediment dynamics management, dykes, etc.
		Surface Water Management	Measures involving physical interventions to reduce surface water flooding, typically, but not exclusively, in an urban environment, such as enhancing artificial drainage capacities or through sustainable drainage systems.
		Other Protection	Other measures to enhance protection against flooding, which may include flood defence, asset maintenance programmes or policies.

Aspects of Flood Risk Management	**Objective**	**Type**	**Description**
Preparedness	Informing the population about flood risks and what to do in the event of a flood; including emergency response: developing emergency response plans in the case of a flood.	Flood Forecasting and Warning	Measures to establish or enhance a flood forecasting or warning system.
		Emergency Event Response Planning / Contingency planning	Measures to establish or enhance flood event institutional emergency response planning.
		Public Awareness and Preparedness	Measures to establish or enhance the public awareness or preparedness for flood events.
		Other Preparedness	Other measures to establish or enhance preparedness for flood events to reduce adverse consequences.
Recovery and Review (Planning for the recovery and review phase is in principle part of preparedness)	Returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population.	Individual and Societal Recovery	Clean-up and restoration activities (buildings, infrastructure, etc); Health and mental health supporting actions, incl. managing stress; Disaster financial assistance (grants, tax), incl. disaster legal assistance, disaster unemployment assistance; Temporary or permanent relocation; Other.
		Environmental Recovery	Clean-up and restoration activities (with several sub-topics as mould protection, well water safety and securing hazardous materials containers); Other.
		Other Recovery and Review	Lessons learnt from flood events; Insurance policies; Other.

Table 2 reproduces the classification of measures as required to the Member States for reporting under the Floods Directive (European Commission, 2013). The Guidance for Reporting under the Floods Directive (European Commission, 2013) defines human health, economic activity, the environment and cultural heritage as “risk receptors”. This terminology is used in the description of the types of measures.

Table 2 shows as well how the paradigm shift is reflected on the types of measures to implement for flood risk management. The traditional approach focused mainly on the protection aspect of flood risk management, especially on structural measures to reduce the likelihood of flooding. In contrast, the Floods Directive proposes and requests Member states to adopt a richer and broader mix of measures, with the objective of both preventing and reducing flood damages to multiple sectors (population, economic activity, environment and cultural heritage).

Protection measures do not focus exclusively on physical solutions but also on restoring drainage or storage capacities of natural systems, the so-called “nature-based solutions”. But most importantly, different types of measures are suggested in the prevention phase of the flood risk management cycle, which act on the second component of “flood risk”, as defined in the Floods Directive (i.e. “the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event”). Thus, these measures prevent or reduce potential damages or the “adverse consequences” associated with a flood event in different ways: (i) avoiding the location of more people or new assets in flood-prone areas; (ii) relocating existing population or assets from flood-prone areas; (iii) reducing the vulnerability of assets in flood-prone areas ("adaptation of receptors"). Other measures proposed to enhance flood risk prevention are mostly directed to improve knowledge on flood risk and flood vulnerability.

As Hartmann et al. (2013) state, the Floods Directive demands participative approaches when it establishes that "Member States shall encourage active involvement of interested parties in the production, review and updating of the flood risk management plans" (Art. 10). The Directive, however, remains vague on its implementation in general and, in particular, on the objectives of participation, which are key for defining collaborative and participative approaches (Hartmann & Spit, 2016). Hartmann & Spit (2016) identify from spatial planning literature four main purposes: Support (increasing citizens' agreement with the plan); Increase quality (adding information to improve the quality of the plan); Approve decision (procedure to approve and "justify decisions") and Education (public information of the plan's contents).

The Tiber Basin Flood Risk Management Plan is selected in order to show an example of how flood risk mitigation measures are organised in a Flood Risk Management Plan. This aspect varies even in the Italian context, with some commonalities, but it depends on how the Floods Directive is interpreted by each river basin district. The Tiber basin Flood Risk Management Plan is organised in a structure that foresees three levels for the application of measures: the river basin district, the homogeneous areas and the areas under significant risk (ARS, "aree a rischio significativo di alluvioni").

The first level includes objectives and measures of a general nature valid at the district/basin scale, which guides action mainly in the form of non-structural measures. These include measures directed to make room for rivers and to maintain or restore floodplains. The plan also indicates that this level must also include the promotion of sustainable land use practice, the improvement of water retention as well as the controlled flooding of certain areas in the event of a flood. At the homogeneous areas or sub-basins level, programs of measures are applied for the regulation of land use for risk prevention and mitigation and the reduction of the vulnerability of exposed assets. This regulation is already in place and in force, defined in the technical norms of the "Piani di Assetto Idrogeologico" (PAI), basin plans already approved for each river basin in Italy, established by the law 183 in 1989. The ARS or areas under significant risk represent "the local level" (as defined by the plan), for which it is necessary to define structural measures to protect the exposed population and built environment or, in some cases, to relocate them.

2.3 STATE OF THE ART: FLOOD KNOWLEDGE BASE IN ITALIAN REGIONAL PLANS

Almost 23 per cent of the Italian territory is under flood risk, which is distributed within all Italian regions (Trigila et al., 2015). It was decided then to study the existing regional spatial plans of all 20 Italian regions. These spatial plans comprise diverse planning instruments with different scopes. The organization of spatial planning competencies into Regional Institutions after the devolution of local power in Italy

(1977) required each of the new Regions to prepare a Territorial Regional Plan (Piano Territoriale Regionale) and a Regional Landscape Plan (Piano Paesaggistico) (De Luca & Lingua, 2014). As De Luca & Lingua (2014) explain, the amendment to Title V of the Italian Constitution (2001) and the approval of the National Landscape Code (2004) introduced important changes in regional legislation that are reflected in current regional spatial plans, which have a common need to overcome the traditional approach of separating the different types of regional planning (spatial, landscape, development planning), with a new mixed model of the regional territorial plan that is simultaneously strategic, structural and operational.

Regardless of the shape and scope of the planning instruments, the objective of the review of the regional spatial plans is to individuate the knowledge base regarding floods, flood hazard and risk that was considered. Other elements are also studied such as objectives, strategies, actions, projects and specific norms aimed at flood risk management. These elements are important to understanding if and how the "flood knowledge base" is used within the plans. All 20 Regions were investigated, however, some of them did not have regional plans in force as to June 2018. This is the case of *Trentino Alto Adige*, *Basilicata* and *Molise* Regions. *Sicily* has no regional plan in force either, only guidelines for the development of the Territorial Landscape Plan, written during the '90s.

In the case of the *Piedmont* Region, the Regional Territorial Plan (Piano Territoriale Regionale - PTR) 2011, of a strategic nature, contains as a strategy "the environmental sustainability, energy efficiency and prevention and protection against natural and environmental risks". A general objective within the environmental sustainability strategy is the prevention and protection from environmental and natural risks.

Specific objectives include the definition of preventive flood risk measures and coordination and enforcement of basin planning and territorial planning. Furthermore, as far as flood knowledge is concerned, the cartography of the PAI (Piano di Assetto Idrogeologico) is considered (flood hazard maps, "cartografia fasce di pericolosita' idraulica"), as well as the prescriptions ("vincoli") that it imposed in terms of territorial transformations.

Piedmont's Regional Territorial Plan introduces also implementing regulation (Norme di attuazione). For each strategy, the plan sets out provisions for spatial planning instruments that, at different levels, contribute to its implementation and to the pursuit of the objectives assumed, by setting guidelines and directives. The guidelines consist of guidance provisions and criteria aimed at territorial and sectoral planning at different levels, to which compliance is discretional. Instead, the directives are characterized by greater specificity and constitute binding provisions, but not immediately preceptive, whose implementation involves the adoption of appropriate tools. According to the implementing norms, in order to prevent flood risk, the plan promotes actions aimed at improving the knowledge of the regional territory, the implementation of structural and non-structural measures for risk mitigation, as well as the definition of planning guidelines and actions consistent with the vulnerability of the regional territory.

The Regional Territorial Plan of *Lombardy* (PTR) 2010 sets between its 24 objectives of different nature to pursue the safety of citizens against risks that derive from the use of the territory, acting on prevention and on the diffusion of knowledge on different risks (from floods to industrial), on planning and on the sustainable use of land and water. In particular, to accomplish the "thematic objective" regarding flood risk mitigation, different actions and measures are contemplated. For example, the renaturalization of pertinent floodplains, the promotion of land use and projects in urban areas that reduce land impermeabilization and guarantee its permeability, the enactment of the PAI of the Po river basin, the promotion of relocation of settlements and infrastructure in flood-prone areas, the development of flood risk prevention through urban planning, the prohibition to construct in flood-prone areas and the activation of mandatory insurance mechanisms for settlements in flood-prone areas.

The knowledge base ("quadro delle conoscenze") on floods of the regional territorial plan of Lombardy includes hazard information (i.e. the PAI and the new FRMP hazard cartography), and some elements of exposure, such as a map of the population in areas subject to floods and landslide hazard, and some of risk (i.e. a map of qualitative risk regarding floods and landslides and one flood risk map from the FRMP). In fact, this knowledge base on risks is envisaged in the Lombardy regional law on Territorial Government of 2005 (l.r. 12/2005) as an element to prevent flood, seismic, geological and landslide risks. Another relevant element is the recent regional law number 4 of 2016 that specifies and governs Lombardy Region's activities related to the protection of the land and the management of watercourses in the regional territory. The law introduces the concept of "hydraulic invariance" ("invarianza idraulica"): With respect to the starting conditions, the water runoff (water flow to rivers) should not be increased with the construction of new residential and industrial buildings, parking lots, roads and redevelopment. A new regional regulation was adopted in 2017 after the promulgation of the former law. The regulation sets a new framework for new constructions and renovation of existing ones, including road infrastructure (Lombardy Region, 2018). The regulation must be applied throughout the regional territory, in a diversified manner depending on the criticality of the area in which it falls: the regional territory has in fact been divided into high, medium and low critical areas (ibid.).

The Regional Territorial Plan of *Emilia Romagna* (Piano Territoriale Regionale - PTR) of 2010, which follows the recent trend in Italian regional planning towards strategic planning (de Luca & Lingua, 2014), defines integrated strategies related to the four dimensions of territorial capital: knowledge, social capital, infrastructure/built-environment capital and ecosystem/landscape capital. The first strategy refers to the development of a widespread system of functional knowledge and learning processes to strengthen Emilia-Romagna in the face of several challenges, including the sustainable management of risks. The last strategy regarding ecosystemic capital calls for the promotion of territorial safety and the development of a "culture of defence against risks", including flood risk, with an approach following the principle of prevention, adequate management and maintenance of the territory and, above all, spatial planning that outlines land uses compatible with the hazardousness of the territory. Despite establishing objectives of risk prevention and knowledge promotion, the knowledge base regarding floods included in the plan is very poor. It refers only to the hazard, at different levels of detail: at a European level presenting a map of mixed flood and landslide hazard, and at a provincial level combining different kind of hazards (earthquakes, floods, winter storms, landslides, fires, droughts, extreme temperatures, etc.) in a unique index. The hydraulic invariance principle in *Emilia Romagna* was introduced within the Basin Plan of the Regional Romagnoli basins in 2003.

Tuscany's Regional Plan (Piano di Indirizzo Territoriale - PIT) 2015, of a "mixed" nature both structural and strategic, defines ten "strategic objectives", none of which recall any aspect of risk prevention or reduction, focused on landscape protection and enhancement. In fact, the PIT has the valence of a landscape plan ("piano paesaggistico") and defines "structural invariants" ("invarianti"), one of which includes the characters of the hydrographic basins and rivers, also recognized as strategic resources for regional sustainable development. According to the plan, this invariant involves the interpretation of different kinds of cartography, particularly hydrogeological and geologic maps.

Concerning the *Umbria* Region, it is possible to appreciate once again the trend depicted by (de Luca & Lingua, 2014), where recent regional plans have a mixed valence between structural and strategic nature. In fact, the Urban Territorial Plan (Piano Urbanistico Territoriale - PUT) from the year 2000 is in perspective being replaced by the Strategic Territorial Design (Disegno Strategico Territoriale – DST), approved in 2008, with an open approach to fostering a closer, strategic connection, with economic planning and with planning developed at local level. Actually, the DST lays the foundations for a revision of the PUT, "in order to move from this current "framework plan" ("piano quadro") to a more functional strategic instrument for the pursuit of the sustainable development of Umbria" (Umbria Region, 2014). Furthermore, the DST is on the one hand strategic and on the other, operational and instrumental. In this regard, the DST includes different projects such as the "Tiber project" and the "Apennine project". The Tiber project has as objectives the integrated management of floodplain areas in relation to protected areas, the urban redevelopment of the areas along the river and the verification and possible redefinition of urban planning for residential and industrial areas along the Tiber. The Apennine project foresees the completion of the measures for safeguarding hydrogeological unstable sites, their preservation and enhancement.

Even though the PUT is being replaced by the DST, according to the regional law of 2015 (L.R. 1/2015 - TU), the cartography remains valid. This cartography includes a map with historically flooded areas, but the cartography is much richer with respect to seismic risk (e.g. risk maps, maps of damages of past events, population exposure and vulnerability maps). Furthermore, the same regional law established in 2015 the Strategic Territorial Program (Programma Strategico Territoriale - PST), which must develop its own strategic action "in coordination with regional economic-financial planning instruments, as well as with European and national programmatic references", pursuing the general objectives of territorial governance. The law outlines the PST as a territorial programming instrument strongly linked to regional strategic choices that are consistent with state and Communitarian development policies, a tool that has the ambition to stimulate organic and integrated planning, providing a coherent background of the development opportunities put in place by the various sectoral policies (Umbria Region, 2017). These policies are translated into plans and programs and the upcoming PST must indicate, among other things, actions needed to mitigate territorial and environmental risk.

The Regional Territorial Landscape Framework (Quadro Territoriale Regionale Paesaggistico – QTRP) of the *Calabria* Region, approved in 2013, interprets the guidelines of the European Landscape Convention (Law 9 January 2006, No.14) and the Code of Cultural Heritage and Landscape (Legislative Decree No. 42 of 22 January 2004) and aims at contributing to the formation of a modern culture of government of the territory and of the landscape. According to the QTRP, risk prevention and reduction emerge as a paradigm to inspire the transformation of the territory by pursuing as a general objective the promotion of systematic knowledge of the regional territory. The QTRP includes a volume dedicated to the knowledge base of the framework, including a knowledge base on territorial risks ("Quadro Conoscitivo dei rischi territoriali"). The aim of this knowledge base is to contextualize each type of risk within the scope of the spatial planning instruments with the purpose of analysis, prescription and intervention both in the general regional planning instruments and in provincial and communal ones. However, the knowledge base regarding floods is almost non-existent, focusing on some elements related to the hazard: recalling some aspects of the PAI (without the hazard maps), describing some important past flood events and by providing synthetic results regarding the percentage of areas at risk in each municipality.

The Regional Territorial Plan of *Valle d'Aosta* (Piano Territoriale Paesistico – PTP) of 1998 defines programmatic lines ("linee programmatiche") by sector (e.g. transport, infrastructure, services, industry, etc.). In the "land and primary resources" programmatic lines, the Region promotes cognitive activities, interventions and disciplinary approaches designed to ensure an effective risk and hydrogeological defence throughout the regional territory, with precaution and limitations of use based on the hazardousness of the various areas, taking into account the activity of the Po River Basin Authority for the development of the basin plan (PAI). Particularly, the Region promotes investigations and in-depth analysis to determine areas at risk of flooding, implementing the determinations made by the PAI for the different flood-prone areas ("fasce PAI"). Furthermore, the Region promotes the renaturalisation of river basins affected by improper works or activities, the recovery of areas suitable for flood lamination, the cleaning of the riverbed, the regeneration of degraded river ecosystems, the relocation of incompatible settlements and the safeguarding of consolidated and compatible ones, water purification and the elimination of polluting sources. Such interventions must be designed with an integrated approach, based on studies extended to the whole river basin and considering hydraulic, hydrogeological, geological, ecological, biological, landscape, urban, historical and cultural aspects. Regarding the knowledge base, the plan provides cartography that includes qualitative flood hazard maps with hazard levels.

Veneto's Regional Territorial Coordination Plan (Piano Territoriale Regionale di Coordinamento - PTRC) 2009, indicates the objectives and main guidelines for the organization of the regional territory as well as the strategies and actions for their realization. Consequently, the PTRC must not be regarded "simply as a territorial transposition of the contents of the Regional Development Programme (Programma Regionale di Sviluppo - PRS), but rather as the design of a vision" (de Luca & Lingua, 2014: 20). This plan contains a knowledge base ("quadro conoscitivo") that is "the set of data, information and map representations that describe the socio-economic, territorial and environmental context, from which the analyses and studies leading to the definition of the objectives are based, and that support the strategic choices made in the plan, with reference indicators that represent the relevance of the goals undertaken by identifying and describing the dynamics of the various sectors" (Veneto Region, 2017). Different maps and indicators regarding mean rainfalls and flood hazard are included in this knowledge base, but none related to flood risk, exposure or vulnerability.

A partial variant of the 2009 PTRC was adopted in 2013 (PTRC Variante 2013) that, among other things, introduces modifications to land protection and flood safety and contains more elements regarding floods. On the one hand, the variant's report comprises a short description of historic floods including the analysis of flooded areas by land use, flood-prone areas classified by land use in the form of a cake chart with duration and water depths of the last recorded flood and existing hydraulic constructions. Furthermore, the variant recalls the different river basin plans (PAI) that interest the Veneto Region, compares the hazard cartography and states that criteria for defining the hazard level used by these programming tools by the various Basin Authorities are not entirely homogeneous. In consequence, a map with flood-prone areas of the Veneto Region is presented, elaborated from the PAIs of the various Basin Authorities, which lacks the distinction between different hazard levels because of criteria incompatibility. On the other hand, a new map was added that indicates flood-prone areas, areas that were flooded in the past 60 years and lamination areas.

The *Friuli Venezia Giulia* Regional Territorial Plan (Piano Territoriale Regionale - PTR) was adopted in 2007, abandoning the purely conformative dimension of the territorial planning of the Regional Master Plan (Piano Urbanistico Regionale Generale - PURG) and defining a more strategic perspective for regional territorial governance (de Luca & Lingua, 2014). The PTR portrays a scenario with different objectives within which the municipalities possess full independence in the governance of the territory (ibid.). The plan contains a volume dedicated to the knowledge base ("quadro delle conoscenze e delle criticita"') organized around "essential resources" (i.e. air, water, land and ecosystems, primary economic activities, landscape, cultural heritage, infrastructure and technologic systems and settlements system). The knowledge base regarding the water resource and floods includes the recollection of the different basin plans that concern the Region. Concerning the actions proposed in the PTR on flood risk, the PTR entrusts municipal and supra-municipal planning territorial instruments the task of identifying the hydrographic network present on the territory of their competence. These instruments, when locational decisions are made, must necessarily take into account the presence of this hydrographic network in order to avoid damages, particularly in urban areas. Furthermore, it is the responsibility of these instruments and their competent authorities the verification of the "hydraulic invariance": in case of land use transformations that substantially change the land coverage or are located in flood-prone areas, projects must provide adequate measures to compensate the extra runoff generated. It is important to note that the regulation regarding the application of the hydraulic invariance principle was approved in April 2018, following what was prescribed by the Regional Law n.11 of 2015.

The new 2015 Landscape Regional Territorial Plan (Piano Paesaggistico Territoriale Regionale - PPTR) of the *Puglia* Region sets general objectives for a strategic scenario, where the first one is "to ensure the hydrogeomorphic equilibrium of river basins". Specific objectives include flood risk mitigation contrasting all activities that do not respect natural river morphology, permeability and water flow direction and through "research and experimental innovative projects". The plan's knowledge base takes the form of an atlas ("Atlante del patrimonio ambientale, territorial e paesaggistico"); however, flood hazard and risk are not depicted in the "hydro geomorphologic" map.

The Environmental Landscape Plan (Piano Paesistico Ambientale – PPAR) of *Marche* Region 1989 is configured as a territorial plan, referring to the entire territory of the region and not only to areas of particular value. The aim of the plan is to protect the regional landscape and it does not foresee any objective regarding flood mitigation. However, a recent law, Regional Law 22/2011, approved after the floods of March 2011, provides for spatial planning instruments and their variants resulting in a transformation capable of modifying the hydraulic regime, the execution of a hydraulic compatibility verification and the provision of compensatory measures aimed at the pursuit of the hydraulic invariance principle. Regulation set after this law in 2014 defines criteria for the hydraulic compatibility verification of territorial planning instruments and hydraulic invariance of territorial transformations.

The Regional Landscape Plan (Piano Paesaggistico Regionale – PPR) of *Sardinia* Region of 2006 pursues the goals of preserving, protecting and enhancing the environmental, historical and cultural identity of the Sardinian territory, protecting the cultural and natural landscape and its biodiversity; ensuring the preservation of the territory, promoting forms of sustainable development. The Plan contains no information nor refers to flood hazard or risk. Nevertheless, the Basin Plan (Piano di Assetto Idrogeologico – PAI) of the Regional Basin of Sardinia enforces the principle of hydraulic invariance all over the Region. This plan states that municipalities, in drafting general planning instruments or their variants, and in drafting implementation-planning instruments, must make certain that land use transformations respect the principle of hydraulic invariance. These planning instruments must also identify and define the necessary infrastructure to satisfy this principle. Moreover, the PAI assigned the Region the role of approving specific regulations with the aim of encouraging the pursuit of the principle of hydraulic invariance also for existing buildings. Operational guidelines for the implementation of the principle of hydraulic invariance (2017) specify that the hydraulic invariance principle must be applied regardless of whether the territorial transformation intervention is included or not in the flood-prone areas defined by the basin plan (*fasce PAI*).

Abruzzo's Regional Landscape Plan (Piano Regionale Paesistico - PRP) of 1990 aims at protecting the landscape, the natural, historical and artistic heritage, in order to promote the rational use of resources and the preservation of the environment. The 1990 Regional Plan does not contain any objectives or actions toward flood risk mitigation or prevention. The only related element included in the knowledge base is a map indicating the location of rivers, only with the goal of preserving existing landscape and resources in that area. The 2004 update of the cartography did not include any new element regarding floods. There is, however, a new Regional Landscape Plan, still in development since 2010, with a different approach to the knowledge base, proposed to be used both to develop the plan and for the assessment of compatibility (environmental and strategic) of plans and programs by decision-makers. This knowledge base, named "map of places and landscapes" (*Carta dei Luoghi e dei Paesaggi*), describes the territory according to the categories of Constraints, Values, Risks, Degradation, Abandonment, Fracture and Conflict. Flood hazard maps are included in the "risks" section. It is important to note that even if the maps are categorised under "risks", they all refer to different kinds of hazards (e.g. floods, landslides and avalanches). None of them considers other risk components, such as exposure and vulnerability.

The *Liguria* Region was the first to adopt a landscape plan: The Territorial Plan of Landscape Coordination (Piano Territoriale di Coordinamento Paesistico – PTCP), adopted in 1986 and approved in 1990. This plan does not consider flood hazard or risk in any way. The Regional Territorial Plan (Piano Territoriale Regionale – PTR) was supposed to replace the PTCP. The project for the Regional Territorial Plan was proposed in 2014; however, its approval process has been suspended. This project included in its knowledge base flood hazard maps of 50 and 200 years of return period.

Lazio's Regional Landscape Territorial Plan (Piano Territoriale Paesistico Regionale - PTPR) 2007 is the planning tool through which, in Lazio, the Public Administration regulates the ways of governing the landscape, indicating the actions aimed at conservation, enhancement, restoration or creation of landscapes (Lazio Region, 2011a). This plan does not pursue any particular goal regarding flood hazard or risk and does not include in the knowledge base any related element. On the other hand, the Regional General Territorial Plan (Piano Territoriale Regionale Generale - PTRG) of the year 2000 defines the general and specific objectives of regional policies for the territory, of the programs and of the sectoral plans of territorial relevance, as well as of the interventions of regional concern. These objectives constitute a programmatic reference for the territorial policies of the provinces, of the metropolitan city, of the municipalities and of the other local authorities and for the respective programs and plans (Lazio Region, 2011b). The PTRG provides directives and general indications, which must be implemented by the planning instruments at local and regional levels in the formulation of the plans and projects. Land protection and prevention of the various forms of pollution and instability are among the general objectives defined in the plan for the environmental system. No specific objectives were defined regarding floods.

The *Campania* Region approved in 2008 the Regional Territorial Plan (Piano Territoriale Regionale – PTR). The plan considers as one of the sixteen strategic directions the management of environmental risks, amongst which hydrogeological risk (landslide and flood risks). The knowledge base included in the plan, in the form of maps, concerns only seismic and volcanic risks, even if according to the Campania Region itself, 16.5% of the regional territory is under flood or landslide hazard (Campania Region, 2007). In the written part, the plan recalls the Basin Plans (Piani di Assetto Idrogeologico – PAI) but does not provide any specific indications or actions. The plan states that both hazard and risk maps are deemed useful for spatial planning, but they are not reproduced nor mention in other ways in the plan.

2.3.1 Hydraulic Invariance Principle

As mentioned, some recent regional planning instruments and legislation introduced new concepts as in the case of *Lombardy*, *Friuli Venezia Giulia*, *Sardinia, Emilia Romagna* and *Marche* with the hydraulic invariance principle. They represent an interesting example of strategies for flood prevention at regional level that are applied at lower spatial scales by lower-level administrative instruments. In this respect, four examples were selected (i.e. Sardinia, Marche, Lombardy and Friuli Venezia Giulia) to highlight the differences between the regulation for the application of the hydraulic invariance defined by the Regions.

2.3.1.1 Introduction and regulation of the hydraulic invariance principle

The first important difference regards the way in which the hydraulic invariance principle was introduced. In the case of *Sardinia*, the hydraulic invariance principle was established within the Basin Plan (P.A.I, Regional Basin of Sardinia), and the regulation regarding its implementation is defined within the Technical Norms. Instead, in *Marche,* the Regional law number 22, promulgated in 2011 after the occurrence of "tragic floods", introduced the need for the verification of hydraulic compatibility and the definition of measures to guarantee the hydraulic invariance principle. The Region following this law set regulation for its implementation in 2014. *Lombardy* Region introduced the principle in the Regional law number 12 of 2005, with the regulation that allows its enactment issued in 2017. Likewise, Friuli Venezia Giulia approved the application of the hydraulic invariance principle following the Regional law number 29 of 2015.

2.3.1.2 The definition of hydraulic invariance and related concepts

In all the analysed cases, the definition of "hydraulic invariance" is very similar, focused on avoiding incrementing surface runoff after urbanisation, transformations or changes in land use. *Lombardy* Region not only enforces the hydraulic invariance principle but also "hydrological invariance", which indicates that also the volumes of surface runoff must not be bigger than the ones that existed prior to urbanisation.

2.3.1.3 The application of the principle

The regulation of *Sardinia* establishes that municipalities must make certain that land use transformations respect the principle of hydraulic invariance in drafting general planning instruments, their variants and implementation-planning instruments. The principle must be applied to the total area affected by the transformation and not to single lots. Municipalities must also define the necessary measures to satisfy the hydraulic invariance principle inside these instruments.

In *Marche*, the hydraulic invariance principle must be implemented in implementation planning tools, general spatial planning tools and their variants that involve an increment in building capacity, an increase in the coverage ratio or introduce land use designations that can increase the exposure to hydraulic risk.

Legislation of *Friuli Venezia Giulia* indicates that regulation concerning the hydraulic invariance principle must be applied to general urban planning tools and their variants if they involve urban-territorial transformations that need geological assessment; to territorial infra-regional plans including port regulatory plans, detailed municipal regulatory plans or municipal implementation plans, if they involve territorial urban transformations; and building projects.

Lombardy Region applies the hydraulic and hydrologic invariance principles to new constructions, including expansions, demolition, total or partial up to the ground floor, and reconstruction independently of the modification or maintenance of the pre-existing built area, urban renewal involving an expansion of the built-up area or a change in the permeability with respect to the pre-existing condition. The principle is applied at the level of a single lot and only to the area affected inside the lot. The hydraulic invariance principle and its regulation in *Lombardy* are therefore implemented at infra-municipal level. Municipalities are suggested to promote the hydraulic invariance principle throughout their territory by means of different mechanisms also for cases not contemplated in the norm.

2.3.2 Conclusions on the flood knowledge base in Regional planning

The previous exploration confirms the heterogeneity of regional planning practices as discussed in De Luca & Lingua (2014). Results of the analysis show that regardless of the shape of the regional plans, there are commonalities in the way they address (or not) the presence of flood hazard and risk in their territory. These results are synthesised in Table 4.

The regional plans' knowledge base takes different forms, sometimes explicitly included as part of the plan volumes, sometimes in the form of an atlas or cartography and sometimes even missing. In any case, the analysis shows that at most only flood hazard information is used to inform planning decisions at a regional level. In the best of the cases, this information is taken from basin plans, namely from P.A.I, given that the new basin plans following the Floods Directive are quite recent (December 2015). In other cases, this knowledge is missing or is combined in a unique index with other hazards, as in the Emilia Romagna plan, making it unusable to support any action towards flood risk mitigation.

Hazard maps from P.A.I present several limitations such as the incompatibility of the criteria used to produce them from basin to basin, as shown in the case of the *Veneto* Region. This hinders the usability of the maps for regions located inside more than one river basin, which fail at creating a unique hazard map covering the region. Furthermore, these maps depict flood hazard in terms of frequency or probability of flooding (as in the "Fasce PAI"), knowledge that is not very indicative for planning. The inclusion of other variables such as the water depth would provide knowledge that is, on the one hand, more intuitive and easier to comprehend. On the other hand, it would support the introduction of more specific actions in the plans that are based on this evidence.

Besides flood hazard information, in very few cases (e.g. Lombardy and Veneto) other knowledge is included either in the form of flood risk maps or as some aspects of flood exposure. The information on flood exposure is very aggregated, generally non-spatial, and useful only to provide a general (still partial) picture of some of the aspects that contribute to flood risk. They do not fully describe flood exposure, containing only some elements like exposed population and land use.

Another important aspect regards the confusion between “risk” and “hazard” in the knowledge base of the plans. For instance, Abruzzo’s new knowledge base includes only hazard maps in the “risks” section and does not consider either risk or other risk components. Similarly, Calabria’s regional plan includes a knowledge base on “territorial risks”, where the knowledge on floods is almost non-existent, including only some elements related to the hazard like precipitation values.

What is more, none of the plans includes any information on the vulnerability of the territory and the elements exposed to floods. This information is key to support the development of the regional plans in the definition of actions and strategies towards flood risk reduction and prevention. The only flood risk maps available do not permit to discern the different risk factors. They provide qualitative risk levels, hiding the exposure and vulnerability factors (that is if the vulnerability is even assessed). In some cases, to simplify flood risk assessments only exposure is considered (i.e. all exposed elements are considered equally vulnerable). Still, understanding exposure and vulnerability is crucial for defining targeted strategies and actions, based on evidence, and that will ultimately be effective in preventing and reducing flood risk.

The heterogeneous nature of current regional plans translates also into different ways to express intentions and actions. As a result, the purpose of the plan is conveyed through different kinds of objectives and goals. Their achievement is pursued through the definition of strategies, actions, guidelines and directives. The review shows that only in half of the Italian Regions some of these objectives, goals, strategies, actions and guidelines in regional plans pursue flood risk prevention or reduction. Regional planning provides common goals and a vision for the future, which must be shared also by planning instruments at lower levels, and flood risk prevention and reduction should be part of this desired scenario. Intentions and actions in plans regarding flood risk are in most cases vague and very general. For example, Piedmont declares as a specific objective the definition of preventive flood risk measures and “promotes” the implementation of structural and non-structural measures, neither of which are defined inside the plan. In addition, except for the case of specific projects, implementation of the actions to achieve the flood risk reduction and prevention objectives is not as clear either.

Some regions (e.g. Lombardy, Friuli Venezia Giulia, Emilia Romagna and Piedmont) propose in their plans actions and strategies of different nature to reduce flood risk and to prevent it. These actions are listed in Table 3. What is striking is that even if these actions comprise a wide range of measures for flood risk management (from protection infrastructure to flood insurance mechanisms), they are not supported by a likewise broad range of knowledge and evidence. In fact, these actions are not even connected to the knowledge base of the plan, which covers at most the hazard aspect of risk and is, consequently, not enough to inform them. For instance, Piedmont’s plan proposes the definition of planning guidelines and actions consistent with the vulnerability of the regional territory, but it does not provide any information regarding this vulnerability nor mentions the need for its assessment. Likewise, the flood risk management actions set in Lombardy’s regional plan are not supported by evidence and either is their implementation if it is to happen. The development of flood risk prevention through urban planning and the relocation of settlements and infrastructure from flood-prone areas, to name a few, require more than knowledge on flood hazard to be defined and then implemented.

Emilia Romagna set in the strategies of the regional plan “spatial planning that outlines land uses compatible with the hazardousness of the territory”; however, the knowledge base only comprises combined hazard maps at European and provincial levels and does not even mention any other useful source of information of the kind (e.g. the basin plans). Friuli Venezia Giulia assigned municipal and supra-municipal planning territorial instruments the task of identifying the hydrographic networks on their territory and to “consider its presence” to avoid damages. Once again, these actions are very imprecise and the knowledge base in the plan is very poor. Additionally, the responsibility of both interpreting and implementing these actions is set on the municipalities, which often have few resources to meet the demands.

Table 3 Actions and measures in current Italian Regional Plans for Flood risk prevention and reduction (source: author).

Actions/Measures for Flood Risk Prevention and Reduction in Italian Regional Plans

- Promotion of land-use and projects in urban areas that reduce land impermeabilization and guarantee permeability.
- Relocation of settlements and infrastructure from flood-prone areas.
- Prohibition to build in flood-prone areas.
- Use of flood risk studies as a tool to support planning activities of local authorities.
- Development of flood risk prevention through urban planning.
- Spatial planning that outlines land uses compatible with the hazardousness of the territory.
- Activating mandatory flood insurance frameworks in flood-prone areas.
- Monitoring hydrogeological risk also through innovative techniques.
- In-depth analysis to determine areas under flood risk.
- Identification of hydrographic networks and flood-prone areas.
- Promoting programs for the construction of infrastructure for flood lamination.
- Verification of “hydraulic invariance” principle.
- Counteracting all activities that do not respect natural river morphology, permeability and water flow direction.
- Integrated management of floodplain areas.
- Urban redevelopment of the areas along the river .
- Verification and redefinition of urban planning for residential and/or industrial areas along the river.
- Coordination of basin and territorial planning.
- Enforcement of basin planning.
- Implementing regulation concerning flood risk prevention and mitigation.
- Implementing the prescriptions defined by the PAI.
- Promotion of territorial safety.
- Development of a "culture of defence against flood risk“.
- Diffusion of flood risk knowledge.

The operational nature of recent Italian Regional plans is reflected also through the presence of programs and specific projects. The Umbria Region with the Tiber project within the Strategic Territorial Design (Disegno Strategico Territoriale – DST) introduced objectives for flood risk mitigation as well as a way of implementing them. Implementing regulation in Piedmont's Regional Territorial Plan (2011) is another example of the operational character of recent plans, which are at the same time strategic. This regulation introduces guidelines aimed at flood risk prevention and reduction. Application of the guidelines at lower planning levels is discretional, while directives have a binding nature.

Guidelines state that spatial planning at the provincial and municipal levels constitutes the instrument through which to implement flood risk prevention policies, consistent with the objectives of the Regional and Basin Plans. In addition, all sectoral plans must deal with the hydraulic characteristics of the territory on which they are set, considering their vulnerability, evaluating the possible impacts and adjusting their actions based on them, also providing for mitigation and compensation if these actions aggravate the vulnerability of the exposed assets or existing risk. Local planning, in the construction of new settlements for productive or tertiary activities, residential, commercial or infrastructure works, must favour the location in areas not subjected to hydrogeological hazard or risk. Nevertheless, as mentioned, these actions are left to the discretion of instruments at lower levels, while binding actions for flood risk mitigation are not included.

In fact, this is an important aspect that concerns many actions for flood risk management in most regional plans, that is that they are weak in their implementation. For instance, the "promotion" of projects that reduce impervious surfaces, the "promotion" of programs for infrastructure and the "promotion" of renaturalisation of floodplains. The action of "promoting" by itself is seldom effective. The way and the means for implementing these actions are not considered.

Another action worth discussing is the relocation of settlements and infrastructure from flood-prone areas, as proposed in the plans by Lombardy and Valle d'Aosta. The relocation of existing settlements is very difficult to implement because it is a sensitive issue, which also requires high political will. In the case of Lombardy, relocation is proposed as a "promotion". This could mean that people willing to relocate could be benefited in some way and not necessarily forced to move and that the regional government might not bear all the costs. In any case, this raises a very sensitive issue regarding the people unwilling to move and with respect to the financial burden that relocation costs would represent to the whole community. A cost-benefit analysis should be performed to evaluate the economic desirability of this kind of measure for specific cases, but it would also require the consensus of the community.

What is key is to prevent the location of these settlements and infrastructure in flood-prone areas in the first place. In effect, Lombardy region sets also the prohibition of the location of new constructions in flood-prone areas as an action, but it does not emphasise it enough in terms of implementation (for example by proposing and establishing stricter controls).

The recent introduction of the hydraulic invariance principle by some regional legislation and regulation represents a step forward in the integration of flood risk management in spatial planning but with a few setbacks. It is still hazard oriented as it foresees the implementation of structural measures to balance surface runoff generated by urbanisation. As shown, the application of the principle varies from region to region, but it assigns generally the municipalities (sometimes other supra-municipal entities) the responsibility of applying the principle.

In Lombardy, the Region can execute random controls to the municipalities to check whether they are implementing the hydraulic invariance principle. In Friuli Venezia Giulia, given that the principle is applied within planning instruments at different levels, the controls are also either done by the region or the municipalities. Since the principle has been introduced only recently, it is not clear yet if it is respected in practice and whether there are problems or irregularities in its implementation.

Undoubtedly, both the proposal and the implementation of flood risk reduction and prevention actions require more DRR knowledge than the one currently present in the knowledge base of regional plans. As shown, knowledge on flood risk and exposure are hardly considered and vulnerability is always missing. Therefore, the DRR knowledge currently used is insufficient for supporting spatial planning for flood risk prevention and reduction at the regional level.

Table 4 Flood knowledge base, objectives and actions in Italian Regional Plans (source: author).

Region	**Regional planning instrument**	**Year**	**Flood-related KW base**	**Objectives, goals, strategies and actions for flood risk mitigation/prevention**
Abruzzo	Regional Landscape Plan (Piano Regionale Paesistico - PRP)	1990	* Map indicating the location of rivers * Flood hazard map	-
Calabria	Regional Territorial Landscape Framework (Quadro Territoriale Regionale Paesaggistico – QTRP)	2013	Knowledge base on territorial risks (“Quadro Conoscitivo dei rischi territoriali”). No flood maps, scarce information on some historic floods.	Strategic action: Territorial risk prevention and reduction.
Campania	Regional Territorial Plan (Piano Territoriale Regionale – PTR)	2008	* Mention of basin plans	Strategic direction: Management of hydrogeological risk.
Emilia Romagna	Regional Territorial Plan (Piano Territoriale Regionale - PTR)	2010	* Map of mixed flood and landslide hazard at European level. * Qualitative map combining different hazards at provincial level.	Promotion of territorial safety and the development of a "culture of defence against risks", including floods, with an approach following the principles of precaution and prevention, and spatial planning that outlines land uses compatible with the hazardousness of the territory.
Friuli Venezia Giulia	Regional Territorial Plan (Piano Territoriale Regionale - PTR)	2007	* Recollection of basin plans that concern the Region	General objective: Increasing level of safety regarding floods. Actions: identification of hydrographic networks and flood-prone areas, verification of “hydraulic invariance” principle. New regional regulation on the application of the hydraulic invariance principle (2018).
Marche	Environmental Landscape Plan (Piano Paesistico Ambientale - PPAR)	1989	* Map indicating the location of rivers and watercourses.	New regional regulation on criteria for the hydraulic compatibility verification of territorial planning instruments and hydraulic invariance of territorial transformations (2014).

Region	**Regional planning instrument**	**Year**	**Flood-related KW base**	**Objectives, goals, strategies and actions for flood risk mitigation/prevention**
Piedmont	Regional Territorial Plan (Piano Territoriale Regionale - PTR)	2011	* Flood hazard maps from the P.A.I * Prescriptions from P.A.I. on territorial transformation	General objective within the environmental sustainability strategy: Prevention and protection from environmental and natural risks. Specific objectives: Definition of preventive flood risk measures and coordination and enforcement of basin and territorial planning. Implementing regulation concerning flood risk prevention and mitigation.
Puglia	Landscape Regional Territorial Plan (Piano Paesaggistico Territoriale Regionale - PPTR)	2015	-	Specific objective: Flood risk mitigation, counteracting all activities that do not respect natural river morphology, permeability and water flow direction.
Sardinia	Regional Landscape Plan (Piano Paesaggistico Regionale – PPR)	2006	* Map indicating rivers and lakes.	Hydraulic invariance principle set by the Basin Plan.
Tuscany	Territorial Plan (Piano di Indirizzo Territoriale - PIT)	2015	-	-
Lazio	Regional Landscape Territorial Plan (Piano Territoriale Paesistico Regionale - PTPR)	2007	* Map indicating the location of rivers	-
	Regional General Territorial Plan (Piano Territoriale Regionale Generale - PTRG)	2000	-	General objective for Environmental System: "Soil defence and prevention of the various forms of instability".
Liguria	Territorial Plan Landscape Coordination (Piano Territoriale di Coordinamento Paesistico – PTCP)	1990	-	-
	Regional Territorial Plan Project (progetto di Piano Territoriale Regionale – PTR)	2014	* Flood hazard maps (50 and 200 years return period)	-

Region	**Regional planning instrument**	**Year**	**Flood-related KW base**	**Objectives, goals, strategies and actions for flood risk mitigation/prevention**
Lombardy	Regional Territorial Plan (Piano Territoriale Regionale - PTR)	2010	* P.AI. and the new P.G.R.A. hazard and risk maps * Flood population exposure map * Qualitative flood risk map	One of the main objectives: Pursuing the safety of citizens against risks that derive from the use of the territory, including flood risk. "Thematic objective": Mitigating flood risk. Acting on prevention and on the diffusion of knowledge on different risks (from floods to industrial), on planning and on the sustainable use of water. Measures and actions of different kinds (from hazard mitigation to exposure reduction and risk transfer through insurance). New regional regulation on hydraulic invariance (2017), for new constructions and refurbishment of existing ones.
Umbria	Urban Territorial Plan (Piano Urbanistico Territoriale - PUT)	2000	* map of historic floods	-
	Strategic Territorial Design (Disegno Strategico Territoriale – DST)	2008		Tiber project's objectives: integrated management of floodplain areas, urban redevelopment of the areas along the river and the verification and redefinition of urban planning for residential and/or industrial areas.
Valle d'Aosta	Regional Territorial Plan (Piano Territoriale Paesistico – PTP)	1998	* Flood hazard maps	In the "soil and primary resources" programmatic lines, the Region promotes in-depth analysis to determine areas under flood risk, implementing the prescriptions defined by the PAI.
Veneto	Regional Territorial Coordination Plan (Piano Territoriale Regionale di Coordinamento - PTRC) and Variant	2009/ 2013	* Flood hazard map elaborated from all PAI * Description of historic floods * Map with historic floods *Computation of flooded areas by land use	-

2.4 STATE OF THE ART: FLOOD KNOWLEDGE BASE IN LOCAL PLANNING

The state of the art on the knowledge related to floods used at Local Planning level is studied in selected EU countries, i.e. Italy, France and Germany.

2.4.1 Italy

The most important instruments at the local planning level in Italy are the "Piano Regolatore Generale" (P.R.G) and the "Variante generale" (general variation). The P.R.G. is a comprehensive land use plan and the "variante" is a modification of the previous plan. The general variation affects only partially the P.R.G., so it does not constitute a plan by itself. It is important to note that some Regions have changed the name and characteristics of this land use plan and have also introduced new instruments. Nevertheless, the P.R.G. and Variants were set nationally and are still widespread. The P.R.G. provides a zoning or land-use map with associated "technical norms", which regulate the admitted uses in each zone.

The knowledge base used for developing these plans at the beginning focused mainly on demography, geographic and historical information, and social and urban problems (Menoni, 2005). With time, environmental analyses accompanying plans grew but mostly concerning ecological issues, until the introduction by some Regions of the geological report (ibid.). The geological report considers geological, hydrogeological and seismic hazards at the municipal level. A map generally accompanies this report.

For example, in Lombardy the map of "geological feasibility" ("carta di fattibilità geologica) is a synthesis of other maps, including the flood hazard map set by the basin plans (Piano di Asseto Idrogeologico, P.A.I.) that defines three flood-prone zones according to the flood return period, to which permitted land uses are linked. This map is a hazard map that classifies the municipal territory in homogenous categories according to the level of hazard in the area and provides limitations to construction and land use (Gazzola, 2018). For example, in Lombardy Region the geological feasibility map is classified into four classes, ranging from "no particular limitations" to "serious limitations" to urbanisation and land use transformations (ibid.). This last class ("class 4") bans new constructions with constant occupation and allows structural protection measures; for existent constructions, demolition without reconstruction is allowed, as well as maintenance and refurbishment without increasing either the surface or volume and with measures to lower their vulnerability (Gazzola, 2018).

An important aspect of all the geological reports is that they are constituted by technical documents provided by geologists, seismologists and hydrologists, and generally contain only hazard information (Menoni, 2005). Whilst risk maps are usually missing, not required by law, and thus not used in ordinary practice to support planning decisions (ibid.). Another issue concerning these documents is the fact that they constitute a separate part or "annexe" of the plans, instead of being integrated within the decisions taken in the plans (Menoni, 2005).

Italian basin plans (P.A.I.) contain flood hazard and risk maps to which prescriptions to land use are associated. These prescriptions set in the basin plans must be respected by all planning instruments at all levels. More recent planning instruments like Milan's "Piano di Governo del Territorio" (P.G.T.) (2012), which replaces the P.R.G. in Lombardy, introduced in their knowledge base not only the geological feasibility map but also the flood hazard and risk maps from the basin plans. However, this knowledge base on floods still constitutes a separate part of the plan. Only the restrictions that are associated with the flood hazard and risk maps, as defined by the technical norms of the basin plans, are mentioned and considered in the norms of the local plan.

2.4.2 France

The local urban plan (PLU, "plan local d'urbanisme") is the main planning document at the municipal level or in some cases at intercommunal level (Republique Française, 2018). It was established in the year 2000, replacing its predecessor the land use plan (POS), in setting the rules of land use, to create also a strategic territorial project. Besides land use zoning, it contains also a non-binding document explaining a certain vision for the territory. The PLU generally covers the entire municipal area with a few exceptions; however, it is not mandatory for a municipality to have a PLU (Republique Française, 2018). The local urban plan and other documents regulating land use must take into account risks associated to natural hazards, as defined by the Urbanism Code ("code de l'urbanisme") (Ministère de la transition écologique et solidaire, 2018).

In this respect, what is particularly interesting in the French case is the Plan de Prévention des Risques (PPR, Risk Prevention Plan), established by the law of 2 February 1995, "law Barnier". The PPR is set at the local level and must be annexed to the PLU. The Risk Prevention Plan is today one of the essential instruments of the State's action in the field of risk prevention, in order to reduce the vulnerability of people and assets to natural hazards. The PPR is a binding document that stipulates penal sanctions for non-compliance and consequences in terms of compensation for natural disasters (Ministère de la transition écologique et solidaire, 2018). The Risk Prevention Plan takes into account all hazards, including floods, but also earthquakes, landslides, forest fires, avalanches, etc.

The preparation of the PPR is conducted by the State services. The PPR is carried out in close consultation with the municipalities concerned, under the authority of the Prefect of the department, which approves it after consultation of the municipalities and public inquiry (Ministère de la transition écologique et solidaire, 2018). These plans must be set for all municipalities highly exposed to natural hazards (about 8,000 out of 21,000 municipalities at risk), while for the rest of the municipalities at risk, risk related issues are to be integrated into planning instruments at the local level (Fleischhauer, 2005).

The purpose of the PPR is to gather knowledge of the risks in a given territory, to delimit exposed areas and define requirements in terms of urban planning, construction and management in risky areas, as well as measures to prevent, protect and safeguard existing buildings in these areas (Ministère de la transition écologique et solidaire, 2018). It helps to guide development towards risk-free areas. The PPR is the responsibility of the State to control buildings in areas exposed to one or more risks, but also in those that are not directly exposed, but where development could worsen them (ibid.). The plan comprises three documents:

- An introductory report that contains the analysis of the phenomena considered, as well as the study of their impact on people and assets, current and future. This report also outlines the principles for developing the PPR and the reasons for the regulations.
- A regulatory zoning map, which delimits the zones regulated by the PPR.
- A regulation that specifies the rules applying to each zone.

The zoning map basically comprises two zones: a strong risk zone (red zone, where new construction is banned) and a medium risk zone (blue zone, conditionally buildable). Gradually, new areas have been created to better take into account the specificity of the phenomena (Peltier, 2008). For floods, some maps now distinguish a specific area for flood expansion and in highly urbanized areas a violet zone has been created, corresponding to a strong hazard zone, but in which it is not possible to prohibit all new construction (ibid.). The zoning map is the result of the analysis of the hazard, exposure and vulnerability but also a matter of social choice: it can establish areas that though being moderately hazardous, if less hazardous alternatives exist, then they cannot be developed (Fleischhauer, 2005). The PPR contains other maps besides the zoning map. The map of historic events (carte de l'analyse des événements historiques), the hazard map and the map of "objects" or exposure and vulnerability map (carte des enjeux) (Fleischhauer, 2005).

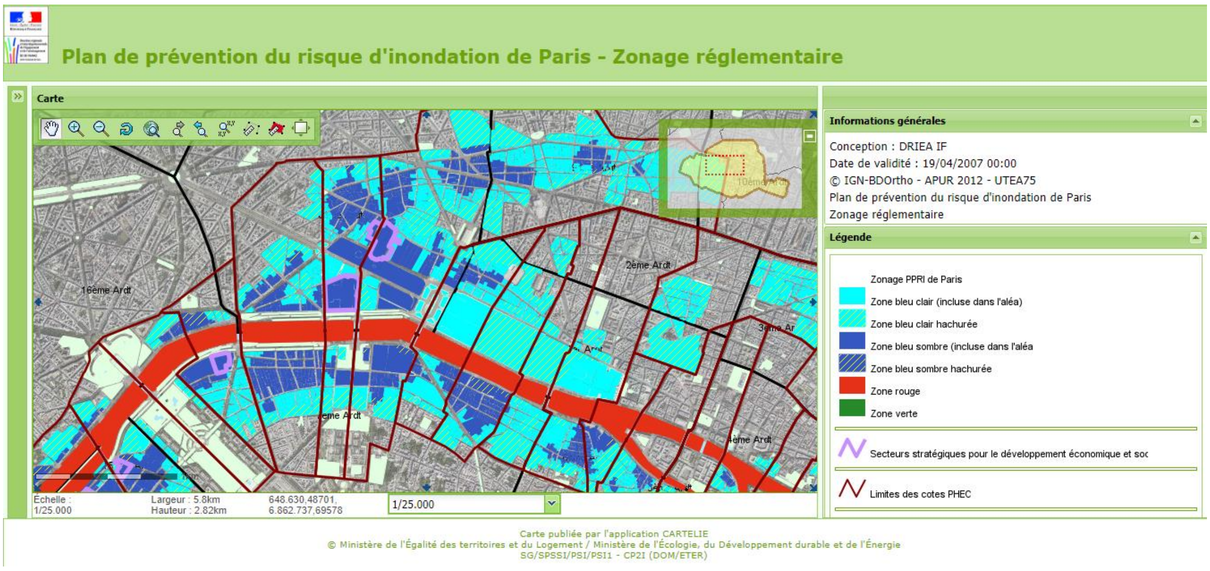
The PPR strongly regulates new construction in highly exposed areas and, in other areas, it ensures that new construction does not aggravate risk factors and it is not vulnerable (Ministère de la transition écologique et solidaire, 2018). Thus, the rules of the PPR are imposed either on future constructions or on existing constructions, but also, depending on the case, on the different possible land uses (tourism, leisure, agricultural or other activities). These rules can deal with urban planning, construction or the management of spaces (ibid.).

2.4.2.1 Plan de prévention des risques d'inondations du département de Paris (PPRI)

The flood risk prevention plan (PPRI) for the Paris Department is selected for study for providing more details on the plan's contents. The PPRI of the Paris Department was last updated and approved in 2007. The hazard scenario selected for the definition of the PPRI is the flooding of the Paris Department, where at the Paris bridges the same water levels are reached as in the flood of January 1910. This flood is considered as centennial, i.e. it is likely to occur on average once every 100 years.

The PPRI includes several types of documents: (i) informative documents, i.e. the introductory report, hazard maps, map of the flood of 1910, exposure/vulnerability map ("enjeux", "what is at stake"); (ii) the regulations and zoning maps by borough or group of boroughs; (iii) an assembly map of all the zoning maps. A piece of the zoning map is presented as an example in Figure 1.

As the introductory report states, the PPRI includes two types of regulations: general requirements applicable to plots, which vary according to their level of risk, and special requirements related to the exercise of a public service function. The requirements related to the parcels are differentiated in three zones defined according to their contribution to the flood: a green zone for the expansion of the flood, a red zone for flood flow and a blue zone that corresponds to the flood-prone urban centre. Within the blue zone, some plots exposed to greater risk are subject to stricter regulation (identified by a darker blue). Requirements related to the exercise of a public service identifies 4 types of services that are particularly vulnerable because of the impact that their dysfunction would have on the safety of people or property and on local, regional or National activities. These comprise public transportation, distribution networks, health care facilities, cultural institutions and administrations.


Plan de prévention du risque d'inondation de Paris - Zonage réglementaire

Informations générales

Conception : DRIEA IF
Date de validité : 19/04/2007 00:00
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Plan de prévention du risque d'inondation de Paris
Zonage réglementaire

Légende

Zonage PPRI de Paris
- Zone bleu clair (incluse dans l'aléa)
- Zone bleu clair hachurée
- Zone bleu sombre (incluse dans l'aléa
- Zone bleu sombre hachurée
- Zone rouge
- Zone verte
- Secteurs stratégiques pour le développement économique et soc
- Limites des cotes PHEC

Échelle : 1/25.000
Largeur : 5.8km
Hauteur : 2.82km
648.630,48701, 6.862.737,69578
1/25.000

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SG/SPSSI/PSI/PSI1 - CP2I (DOM/ETER)

Figure 1 Example of zoning map of PPRI Paris Department (source: http://cartelie.application.developpement-durable.gouv.fr)

The primary purpose of the green zones is to allow water retention for flood lamination. Therefore, this space needs to be as free as possible of any volumetric construction. The regulatory constraints defined for this zone are intended to prevent any increase in flood risk and to guarantee water retention while allowing reasonable use of these spaces.

The red zone is the main flow zone of the river during floods. This area must be kept as free as possible to avoid obstacles to water flow. It includes the river bed and the areas that contribute to the natural river flow. The regulatory constraints associated with the red zone are intended to avoid reducing the flow capacity of the river. It is recalled that installations, structures, activities, permanent or temporary, present on red zones are likely to affect the free flow of water. Therefore, they are subject to authorization, associated with the completion of an impact study that must include impacts on the river flow. The use of these areas is restricted to activities related to the port, the river or the river banks.

The blue zones correspond to urban areas that are flood-prone. It comprises two kinds of areas: dark and light blue. The dark blue area corresponds to large building areas exposed to submersion levels potentially greater than one meter. The light blue area comprises the rest of the flood-prone area, excluding the green and red zones. The regulation of the blue zone has the following objectives:

- Reduction of the number of activities that may pose a risk to the environment in the most hazardous areas, to prevent damage to the environment when flooded;
- risk reduction by prohibiting the storage of sensitive or expensive goods in flood-prone levels, except if special measures are taken;
- limiting direct exposure of houses to flooding;
- and, for new constructions, the obligation to integrate flood risk knowledge into the construction techniques and in the occupation of flood-prone levels.

To achieve these objectives, the PPRI partially limits the constructability allowed in Paris in relation to the existing situation. Being Paris such an important city for the economic and social development of France, construction is accepted in several strategic areas that are key to the development of the city (indicated with a purple line). The development of these zones requires that strict measures are taken. Constructability is also allowed for the social facilities, educational, sports or cultural, necessary to guarantee the quality of life in Paris. These constructions must not increase the number of people that would require evacuation in case of floods and must not increase the cost of damages, by setting their operating level above the highest water levels known.

The regulation specific to each zone and sub-zone is presented in Table 5. Regulation related to the exercise of the public service function of transportation requests operators the development and implementation of a flood mitigation plan. These concession companies of public transportation networks must analyse their vulnerability and integrate into their projects all the appropriate constructive measures to allow the normal operation of the lines, or, at least, to bear, without structural damage, a prolonged immersion of several days. Besides, functioning must be resumed as soon as possible when the water recedes. The plan must include measures intended to reduce the vulnerability of the existing network, measures to reduce the vulnerability of future equipment and facilities, measures to be taken during the flood to prevent damage and to ensure a minimum service of public transport, and the monitoring and restoration procedures of the network after the flood. Regarding the distribution networks (water, energy, telecommunications, etc.) operator companies must analyse their vulnerability and integrate into their projects all appropriate measures aiming to allow their normal operation or, at least, to bear without structural damage a prolonged immersion of several days while ensuring the fastest possible restart of their service. These companies must also produce a flood mitigation plan.

Heads of healthcare facilities in flood-prone areas must perform a detailed analysis of the vulnerability of their institution to floods, and, after this analysis, take measures to reduce this vulnerability. They must guarantee a continuous operation as long as the establishment remains accessible by the usual means. For institutions rendered inaccessible by the flood, those responsible must take all necessary steps to ensure that the residents remain on site while ensuring their safety and the continuity of their care. If this is not possible, the head of the establishment must then, in agreement with the police and the health authorities, draw up a plan for the evacuation and rehousing of the residents in accommodation structures located outside the flood-prone area.

Table 5 Regulation in Paris PPRI by zone (source: author, based on the PPRI).

Zone	**Sub-zone**	**Regulation**
Green	-	All new construction is prohibited, except for 1. existing installations, equipment, activities or constructions, 2. sports or leisure fields, 3. parks and gardens, 4. campsite at the Bois de Boulogne, 5. reception and temporary parking areas of mobile vehicles, 6. accommodation of the guards of the above facilities. New construction must be set above the maximum water level known.
Red	-	Activities at red zone: 1. port activities and equipment, 2. the operation of the waterway, 3. the transport of persons or goods by water, 4. activities enabling the touristic use of the banks and the river. Admitted (if they are intended for activities related to the red zone): 1. reconstruction of buildings within the limit of the existing net floor area, 2. the buildings and technical equipment necessary for the activities present in the zone, 3. in periods with a lower risk of flooding: temporary, demountable or mobile constructions.
Blue	All	Specific provisions for new constructions in the blue zone: - Levels below the maximum known water level exclude any dwelling. - The construction techniques and materials used must ensure the structural sustainability of the buildings despite prolonged immersion for several days (for information purposes, the flood of 1910 lasted 40 days). - Buildings should provide, when possible, access to a road that allows to non-flooded reach areas by roads submerged by less than one meter of water. Construction of public, semi-public or private social, educational, cultural or sporting, under the following conditions: - Electricity, gas, central heating, water (drinking water and sanitary hot water) and telephone distribution networks must be organized to ensure functioning in a flood like the one in 1910. - Construction measures to guarantee the protection of property and people against damage from a flood like the 1910 flood. - The operating levels of this equipment must be installed above the maximum known water level. - Plan for the population and shared, to define access to areas not flooded.
	Violet	Specific provisions for strategic sectors for economic development or of Paris or of national interest: - Electricity, gas, central heating, water (drinking water and sanitary hot water) and telephone distribution networks must be organized to ensure functioning in a flood like the one in 1910. - Construction measures to guarantee the protection of property and people against damage from a flood like the 1910 flood. - Inland routes to the area are set above the highest known water levels. - Plan for the population and shared, to define access to areas not flooded.

Zone	Sub-zone	Regulation
	Dark blue	Establishments falling under the legislation on installations classified for the protection of the environment are not allowed if/for: - Existing establishments cannot be extended as of the date of approval of this plan, - Establishments without authorization, - Establishments must take all the necessary measures to withstand prolonged flooding and to guarantee the absence of damage to the environment during this submersion. * Change of destination of premises having their floor below the maximum known water depth cannot be made in favour of housing.
	Light blue	- Establishments covered by the legislation on classified installations for the protection of the environment are authorized subject to taking all the necessary measures to support a prolonged submersion and to guarantee the absence of damage to the environment during this submersion. - The change of destination of premises having their floor below the maximum known water level may be in favour of housing if at least 50% of the net floor area of each of the dwellings created is located above this level. It is the same in case of rehabilitation of a building for housing below the maximum known water level.

Regarding cultural heritage, given the importance of the cultural and historical heritage endangered by floods, officials of cultural institutions and administrations located in flood zones need to make a detailed analysis of the vulnerability of their institution. A plan must be produced for this end, specifying the measures to reduce this vulnerability and safeguard the threatened heritage.

2.4.3 Germany

The most important local planning instruments in Germany are the preparatory land-use plan (Flächennutzungsplan) and the binding land-use plan (Bebauungsplan) (Pahl-Weber & Henckel, 2008). The preparatory land-use plan covers the entire municipal territory and sets the main features of the different land-uses (Greiving, 2005). The binding land-use plan generally covers part of the municipality, because there is no legal duty to develop it for the whole municipality (Greiving, 2005). The binding land-use plan is based on the preparatory land-use plan and contains legally binding designations on permitted land-uses (Pahl-Weber & Henckel, 2008).

Land use planning in Germany considers flood risk management only by following the zoning ordinances that limit land use in flood-prone areas (Greiving, 2005). These ordinances are not retroactive and do not address the existing built environment, neither the areas behind dykes (ibid.). The 2002 flood in Germany exposed that spatial planning for flood risk prevention played an insignificant role and since then this issue has received large attention also due to the Floods Directive (Thieken et al., 2016b). However, the situation still has not changed much, even with the availability of knowledge in the form of flood hazard and risk maps in all German States, and there are still no development restrictions for areas behind dykes (ibid.). The Federal Building Code states that compensation must be paid by the municipality when the permitted use is changed or withdrawn in the binding land use plan, which drives municipalities to prefer the implementation of structural measures, partially financed by the federal states or by EU funds (Greiving, 2005).

2.4.4 Conclusions on the flood knowledge base in local planning

The review shows that in Italian local plans flood hazard maps, and rarely risk maps, from the basin plans are sometimes present in the knowledge base. However, this knowledge base still constitutes a separate part of the plan that is not integrated into planning decisions. Local planning is still focused on the different restrictions associated with the flood hazard and risk maps in basin plans or in the feasibility maps.

The French case is special because of the existence of a plan (PPR) at the local level with the sole objective of risk prevention and reduction. The knowledge base of this plan considers not only hazard information but also exposure and vulnerability. However, the synthesis of this plan is still represented by a risk zoning map that establishes different constraints to development. What is particularly interesting of these restrictions is that they apply in some cases also to existing constructions, besides development and redevelopment. As the law mentions, this plan must be "annexed" to the local urban plan (PLU), which should set land-uses considering the risk to natural hazards. The PPR then risks being just an "annexe" of the PLU, with its knowledge not really integrated within land-use and locational decisions, as in the Italian case. Nevertheless, it is important to recognise that the restrictions from the PPR in France are much more evolved than the ones in Italy and based on a wider knowledge base.

Local plans in Germany follow the restrictions imposed on new development, whereas existing constructions are not addressed, and neither are the areas behind levees. Currently, flood hazard and risk maps are available for the whole German territory, however, this did not have an impact on the role of spatial planning in flood risk management (Thieken et al., 2016b).

3 REVIEW ON DISASTER FORENSIC INVESTIGATION AND DAMAGE DATA

The present chapter presents the results of an exhaustive literature review on existing approaches for Disaster Forensic Investigation in the Disaster Risk Reduction (DRR) field. Methods are presented and considered regardless of their specific objectives. The second part of the chapter describes the state of the art on disaster damage data collection in international policies. This permits to individuate the disaster damage data, and the post-flood damage data in particular, that are required for forensic investigation. Last, the damage data collection process is analysed in practice in the European context to understand data availability.

3.1 REVIEW OF EXISTING METHODS FOR FORENSIC INVESTIGATION OF DISASTERS

Forensic investigation applied to the study of disasters is relatively new. This kind of studies has been conducted with multiple purposes, from assigning blame in judicial or semi-judicial processes to improving emergency management procedures or safety at the workplace. Most of the existing methods and applications in the literature focus on one particular aspect or try to answer a specific question. For instance, what went wrong during emergency management procedures of the Civil Protection (e.g. *retour d'experience* by the Directorate of Defence and Civil Security, DDSC, *Direction de la Défense et de la Sécurité Civiles*, in France) or who is to blame for a specific damage in environmental disasters (e.g. Shiurman & Slosson, 1992, in the United States).

None of the applications of disaster forensic investigations so far is aimed at supporting spatial planning of any kind. It was only in the very recent years that new approaches were proposed to pursue a comprehensive investigation of disasters. These methods are not intended to seek or assign legal responsibility, nor to focus only on one aspect, but to understand which factors and how they contributed to the gestation and occurrence of a disaster. These approaches fall under what I call in this research the "Disaster Forensics" umbrella, i.e. methods developed ad-hoc to study disasters from a comprehensive perspective.

Table 6 presents some examples of methods and approaches organised by typology: Disaster Forensics, Forensic Engineering, Emergency Management oriented, Judicial purposes and Incident investigation techniques. The "Disaster Forensics" typology comprises the FORIN methodology by the IRDR, the Post-Event Review Capability (PERC) by Zurich Insurance Group and ISET-International, Detecting Disaster Root Causes framework and tool by the German Committee for Disaster Reduction (DKKV) and Forensic Disaster Analysis in Near Real-Time by the Center for Disaster Management and Risk Reduction Technology (CEDIM). Methods grouped in "Forensic Engineering" comprise forensic engineering itself (as defined in the next section), as well as forensic hydrology. Approaches under "Emergency management" focus on the analysis of the crisis management process, where the After Action Reports in the United States are another example, with an approach borrowed from the military. The "Judicial purposes" typology groups all the inquiries with the objective of assigning responsibility after a disaster. Last, the "Incident investigation techniques" comprise methods generally used to investigate different types of incidents and technological accidents, developed in the field of safety management and recently applied to disasters from natural hazards including floods. All the methods for forensic investigation are discussed next.

Table 6 Synthesis of existing methods for forensic investigation (source: author).

Typology	Example of Methods/Approaches
Ad-hoc methods "Disaster Forensics"	PERC Post Event Review Capability (Zurich Insurance, 2015)
	FORIN Forensic Investigations of Disasters (IRDR, 2016)
	Detecting Disaster Root Causes (DKKV, 2012)
	Forensic Disaster Analysis in near real time (CEDIM, 2012)
Forensic Engineering approaches	Forensic Flood Hydrology approach (Loaiciga, 2001)
	Methodological Guide for the Forensic Analysis of Floods (Ramirez, 2015)
	Environmental case histories (Shiurman & Slosson, 1992)
Emergency Management oriented	Retour d'experience (DDSC, 2006)
	After Action Reports (USA)
Judicial purposes	Quasi-Judicial Inquiries (Australia)
	Judicial Retour d'experience (France)
	Environmental case histories (Shiurman & Slosson, 1992)
Incident Investigation Techniques	Sequence Diagrams
	Fault Tree Analysis
	Root Cause Identification
	Causal Tree Method

3.1.1 Forensic Engineering

The term “forensic” originally comes from the Latin word “forum”, a public square or marketplace outdoors where people used to gather in ancient Rome to discuss judicial matters. Therefore, the word “forensic” used in “forensic investigation” or “forensic science” generally means that some parts of the analysis will be related to the law, the courts, adversarial debate, or public debate and disclosure (Noon, 2009). One of the first sciences used in the forensic investigation was medicine, for pursuing criminal investigations. In fact, it is also from ancient Rome where one of the earliest forensic medicine reports comes from, dated from 44 B.C.E after the stabbing of Julius Caesar (Stefoff, 2010).

Besides criminal investigation, forensic analysis has been used for environmentally related failures and disasters, particularly by engineers and geologists, called upon to be expert witnesses in litigations. These include also liability suits resulting from floods and landslides and another type of natural-hazard related damage (Shuirman and Slosson, 1992). There are different situations that can generate this kind of suits (e.g. government agencies vs. private individuals or between private individuals), however, regardless of this fact, “the individual bringing the suit claims that the party being sued has caused or increased the natural hazard damage” (Shuirman and Slosson, 1992: xiii). This gave rise to “Forensic Engineering”, defined as “the application of the art and science of engineering in the jurisprudence system, requiring the services of legally qualified professional engineers” (Carper, 1989).

Different books and manuals have been written to support the work of engineers and geologists dealing with the procedures to conduct a forensic investigation in such context and on how to be an effective expert witness during litigation. The aim of forensic engineering, in general, is to explain an event or failure (in terms of who, what, where, when and how); in other words, to reconstruct what happened, starting from a known end result, gathering evidence to “reverse engineer” how the failure occurred (Noon, 2001). In order to achieve this goal, a forensic engineer needs to gather information from multiple sources: from field work to newspapers, photos, films and interviews with government officials or employees in general. After data collection, much of the investigation involves its interpretation. According to Carper (1989), data will always be incomplete and, in some cases, redundant: redundant evidence allows the forensic engineer to cross-check conclusions.

> *In essence, a forensic engineer: assesses what was there before the event, and the condition it was in prior to the event; assesses what is present after the event, and in what condition it is in; hypothesizes plausible ways in which the pre-event conditions can become the post-event conditions; searches for evidence that either denies or supports the various hypotheses; applies engineering knowledge and skill to relate the various facts and evidence into a cohesive scenario of how the event may have occurred* (Noon, 2001:2).

Besides traditional characterisations of “Forensic Investigation”, there are other definitions in the field of Forensic Engineering with a broader meaning such as the one by Shiurman et al. (1992:1):

> *[Forensic investigation] implies the scientific investigation of accidents and environmentally related failures and disasters in order to discover their causes. These investigations can be made for many*

> *reasons, and their findings and conclusions can be used in myriad ways. A forensic investigation need not necessarily be performed for legal purposes nor result in litigation. However, most are done for legal reasons, with lawsuits being filed in advance of any serious forensic work.*

In fact, Shiurman and Slosson (1992) show in their book how findings of forensic investigations of different case histories, performed originally with pure legal motivations, help to answer questions such as how the disaster could have been avoided or mitigated, how future similar disasters might be avoided and, more in general, what can be learned in terms of future planning and design as well as public policy. It is important to note that whether it is the case of a flood, a landslide or a fire, the focus of the investigation is in the contribution that different factors had to the hazard (e.g. how the operation of a dam provoked a flood of longer duration downstream or how the water infiltration due to development without a sewage system contributed to a landslide activation).

3.1.2 Forensic Hydrology

Forensic hydrology can be regarded as a branch of forensic engineering or more specifically as located "in the intersection of environment science forensic and engineering forensics" (Ramirez and Herrera, 2016). It regards issues like water pollution, floods, droughts and hydraulic infrastructure operation, sometimes with the objective of reducing damages and sometimes for improving water management (ibid.).

Forensic flood hydrology is defined as "a branch of hydrology that supports legal investigations and that deals with the study of flood events with the objective of determining probable causes and sources of human-induced contributions to flood damages" (Loaiciga, 2001). The approach defined by Loaiciga (2001) combines climatic, hydrologic and hydraulic models to distinguish the causes of flood damage. The method was applied to the San Luis Obispo Creek in California, a basin that experienced significant flood-plain development in 25 years. It is based on the fact that flood-plain development increases hydraulic roughness, which at the same time increases the water level for a fixed river flow rate, augmenting the damages associated to a flood of a certain return period and, thus, increasing flood risk. The approach is strictly quantitative, based on the results of hydraulic modelling in terms of the contribution of each "flood factor" (e.g. an orchard farm, a bridge and vegetation) to the water level.

Another interesting methodological contribution in the field of forensic hydrology was made by Ramirez et al. (2015), who follow a more holistic approach, combining hydrometeorology and hydraulic analysis with the "integrated analysis" of political and social data. The final diagnosis is based on the integration of these analyses in order to "objectively" identify causes and effects, lessons learned, and a proposal of possible actions oriented to mitigate the damages of future flood events.

3.1.3 Retour d'Expérience (REX) in France

France has a long tradition in the use of what they call "retour d'experience", that can be translated as "return of experience" or "feedback". As Leone (2007) explains, the *retour d'experience* (REX) in France has many definitions and different approaches. It is mainly used in an organisation to identify the causes of an accident or failure in order to learn from them. However, it is not limited to the understanding of failures but also to the identification of positive actions (Leone, 2007).

The REX, with origins in the analysis of industrial accidents and failures, after some decades started to be applied to major technological accidents as well as to natural disasters (Leone, 2007). One of the first REX in France for natural disasters was performed by Alfred Lacroix in 1904 after the volcanic eruption in Martinique, which marked the beginning of modern volcanology (ibid.). Since then, different REXs were developed, mainly to identify responsibilities, but without a formal and systematic application (Leone, 2007).

It was just in 1998, after the report on the evaluation of public policies for the prevention of natural risks (Commissariat Général du Plan, 1997), that the Ministry of the Environment commissioned the nowadays General Inspection of the Environment (Inspection Générale de l'Environnement, IGE) a mission about the possible organisation of REX on natural risks. In particular, "to examine the benefits that a systematisation of the retour d'experience would bring, the pertinence of the distinction between events at the local and national level and the organisation of a retour d'experience for local events, the preparation of a guide and the definition of statistical indicators relevant for the national level" (Barthelemy, 1999: 7, translation by the author).

In their report, Barthelemy et al. (1999) associate the systematisation and organisation of the retour d'experience with the improvement of the data available regarding some of the damages due to catastrophes. According to the authors, significant data about insurance reimbursements are available since 1982 (when the law for insurance against natural catastrophes, CAT-NAT system, was issued). However, they are not sufficient for the conduction of a REX. On the one hand, the CAT-NAT system does not cover all types of hazards and, on the other hand, not all damages are covered either. For example, compensation of damages to crops are covered by other insurance, the "calamites agricoles" regime, which also covers damages due to other phenomena. Barthelemy et al. (1999) state that in order to be comparable at an international level, all types of natural risks must be considered, regardless of their compensation system. In fact, the first condition for the organisation of the REX is to establish "a solid national database" for all natural hazards, including damages and compensation regarding past events, since 1982 (establishment of CAT-NAT system) and before. This database would allow performing several statistical analyses of the damages due to different hazards (Barthelemy et al. 1999).

Benefits of the implementation of a REX at the national level include the data collection of causes and consequences of natural catastrophes, to better understand natural risks, their material and human impacts, as well as the efficiency of prevention and mitigation measures. These data are likewise useful as input for other types of studies, particularly for understanding vulnerability (Barthelemy et al., 1999). At the local institutional level, benefits of a good organisation of a *retour d'experience* consist of improving the knowledge on vulnerability, revising documents for risk prevention (or to develop them if missing), revising urban planning documents and reducing vulnerability during reconstruction, among others (ibid.).

In 2003, after the experiences of the then-recent catastrophes in France (the 1999 storm, the explosion of the chemical factory AZF in 2001 and several important flood events), the Ministry of Interior (Ministere de l'Interieur et de l'Amenagement du Territoire, MIAT) issued a circular in the official bulletin regarding the organisation and development of the REX for the management of crisis of public safety and civil protection. Prefects were asked to organise locally a retour d'experience after emergencies. This marked the beginning of a systematic and formal application of a REX methodology after every Civil Protection related emergency. The ministry of interior issued in 2006, in collaboration with the DDSC (Direction de la Defense et de la Securite Civiles), a methodological guide for the "REX technicians". It states that "the REX is mainly intended to identify ways to progress, useful locally, and, in a second step, to be analysed by the central administration to capitalise on good practices and to identify recurrent problems" (MIAT/DDSC, 2006: 7, translation by the author).

3.1.4 Disaster Forensics

The methods presented next were specifically designed to investigate different kinds of "disasters" (i.e. man-made disasters, disasters that result from natural hazards and a combination of both). They were all developed in recent years.

3.1.4.1 FORIN (IRDR)

It is particularly relevant in an international context the FORIN methodology (Forensic Investigations of Disasters), defined for the first time in 2011 and recently revised in 2016, by the IRDR (Integrated Research on Disaster Risk). The FORIN project was originally motivated by an issue raised by White et al. (2001) more than 15 years ago and still relevant today: Why are disasters apparently becoming more frequent and economic losses continuing to increase, even if there are greater scientific knowledge and technical capacity? (IRDR, 2011). It aims since its first version to provide a more in-depth understanding of disasters, pointing to the more underlying, sometimes longer-term, root-causes of disasters. The FORIN methodology is defined as the investigation of the root causes of disaster risk and occurrence in order to identify underlying causes in such a way that they can be evaluated and addressed through policy and practice. Therefore, one of the objectives is to provide policy options and evidence-based alternatives or measures to reduce disaster risk.

"The FORIN approach is based on the idea that the magnitude of losses and damage can in large part be explained by human actions and choices when faced with physical hazard, including the choice to ignore them or dismiss their significance" (Oliver-Smith et al., 2016:19). According to FORIN, exposure and vulnerability, concepts that have emerged as strong explanatory variables of disasters in the last 40 years, are seen "simply as facts" and the focus has not gone far enough in searching for causal mechanisms that can help to create effective policies and management strategies; there is a lack of explanations on why and how these conditions exist in the first place and how they developed over time. Hence, FORIN proposes a framework for the explanation of disasters' causality that moves from the more immediate "unsafe conditions" (patterns of exposure and vulnerability) to the more profound fundamental causes. FORIN clearly takes a more political and social oriented perspective, more focused on the social and political context that has favoured the disaster and less on the technical or structural aspects and failures, as opposed to Forensic Engineering.

FORIN's methodology is structured around a causal chain, incrementing the level of analysis, starting from a descriptive analysis (immediate descriptive causal relations), moving to risk drivers or dynamic processes and finally arriving at the root causes. Consequently, the analysis starts with a descriptive analysis of some key areas of investigation: the triggering event(s), exposure of social and environmental elements, the social and economic structure of exposed communities and institutional and governance elements. The aim is to identify existing conditions but not explain them as such (which will be done in the following steps). The guide includes a non-exhaustive list of questions for each research area.

The next step involves the definition of the risk drivers, which explain existing risk patterns. The prior step identified the "immediate descriptive causal relations" but it does not allow to understand why "unsafe conditions" exist as such (Oliver-Smith et al., 2016). It is necessary then to delineate the risk drivers or "dynamic processes" (Wisner et al., 2004), which will be then linked to underlying, structural or root causes. The aim is to provide a more profound explanation by ascribing causality by "moving back one more link in the causal chain to reach out to more profound, culturally, socially, ideologically, pragmatically and politically assigned values and outcomes and their relation to the dynamic processes or risk drivers identified in each case" (Oliver-Smith et al., 2016: 29). The FORIN framework provides some questions related to the "more and well accepted" risk drivers to guide the research (i.e. population growth and distribution, urban and rural land use patterns and processes, environmental degradation and ecosystem service depletion and poverty and income distribution).

Finally, the last step involves the most complex analysis of relating these risk drivers to root causes, considering social, economic, political and environmental relations, processes and evolution within the society's historical context (Oliver-Smith et al., 2016). Four basic approaches are suggested to identify the root causes of a disaster: Retrospective Longitudinal Analysis (RLA), FORIN Disaster Scenario Building (FDSB), Comparative Case Analysis and Meta-Analysis. As the guide explains:

> *The approaches are based on the premise that a causal chain must be empirically established between the patterns of damage and loss in a disaster and those social forces that mobilize the construction of risk, examining root causes and particular expressions of exposure and vulnerability (…) This perspective presents a significant methodological challenge in that the roots of causality are real in a phenomenological sense, but may not be empirically observable. They do, however, operate as structural mechanisms with enduring properties that generate actual conditions that can be directly observed (*Oliver-Smith et al.*, 2016: 32).*

The choice of method will depend on the research questions and the kind of data believed to be useful for the analysis. FORIN recognises the need to continue doing more forensic investigations that permit to recognise more root causes and gather evidence. Some possible root causes mentioned by FORIN (Oliver-Smith et al., 2016) include poverty and inequity, lack of adequate policies, the race for economic advantage between the population or the private-public sectors, corruption, the abuse of common resources for individual gain, etc.

3.1.4.2 The PERC Method

Another interesting contribution to the forensic investigation of disasters was made by a private company, the Zurich Insurance Group, which has developed its own methodology named PERC (Post Event Review Capability) and a methodological manual (Venkateswaran et al., 2015). PERC is defined as a methodology for holistically and systemically analysing disasters in order to provide actionable input for informing policy and practice in disaster risk reduction (Keating et al., 2016). The analysis of what happened and why is structured around the risk management cycle (i.e. preparedness, response and recovery phases) and by examining the "three major components of resilience" (i.e. systems, institutions and agents). The final product of the PERC process is a structured report, which acts as a guide to conduct the investigation. The analysis is based on data gathered from a "desk review" (existing reports, newspaper articles, peer-review articles and opinion pieces on the event and on its context) and on informal and semi-structured interviews from fieldwork (Venkateswaran et al., 2015). The report includes sections about the socio-economic conditions that built-up the risk prior to the disaster, successes in the disaster risk management cycle and actionable recommendations, focusing not only on what went wrong but also on strengthening what went well.

Part of the analysis is supported by an institutional landscape map, useful for identifying the actors involved in the disaster management system (across different administrative scales), showing key decision-making and communication channels and detecting bottlenecks in the system or failures (Venkateswaran et al., 2015).

3.1.4.3 Detecting Disaster Root Causes (DKKV)

The German Committee for Disaster Reduction (DKKV) developed in 2012 a framework and an analytic tool to detect disaster root causes based on a matrix approach (DKKV, 2012). On the one hand, it has in common with the FORIN methodology the analysis of causal linkages between disaster impacts and underlying root causes. On the other hand, it shares with PERC the fact that the disaster risk management cycle is integrated into the analysis approach because it is assumed that limited risk management capacities or failures in risk management can aggravate or extend the crisis (DKKV, 2012).

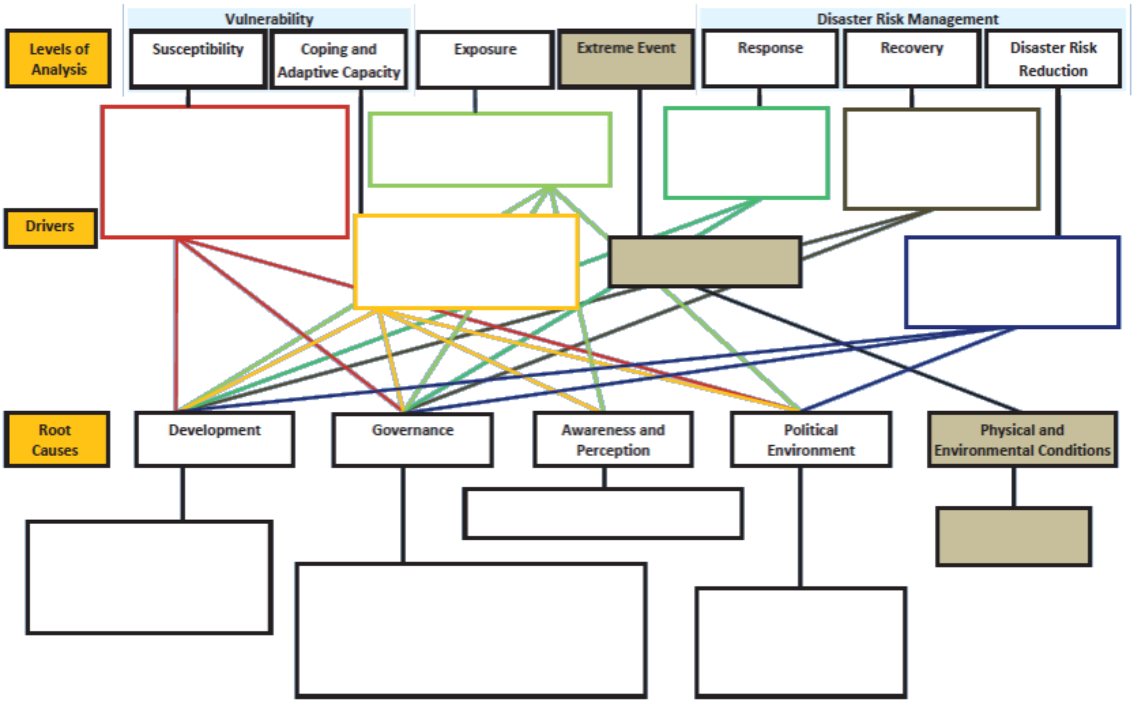


Figure 2 Disaster root cause analysis framework (source: DKKV, 2012)

Originality of this framework is the systematization of root causes in different categories: "development", "governance", "awareness and perception", "political environment" and "physical and environmental conditions". "Development" contains factors related to the national level of development; "Governance" includes factors related to international as well as national policies and governance issues with regard to disaster risk management; "Awareness and Perception" are reasons for failed perceptions as well as the influencing factors; "Political Environment" considers aspects like political instabilities or wars and "Physical and Environmental Conditions" include natural climate variability, climate change and geophysical conditions.

3.1.4.4 Forensic Disaster Analysis in Near Real-Time (CEDIM)

The Center for Disaster Management and Risk Reduction Technology (CEDIM, the Karlsruhe Institute of Technology and the Helmholtz-Centre Potsdam) began in 2011 a new research program, named Forensic Disaster Analysis, based on the interdisciplinary analysis of disasters in near real-time (Prizzia, 2016). CEDIM'S Forensic Disaster Analysis (FDA) pursues the same goal as FORIN program but acts as a complement by providing reports and analyses only a few hours to days after the disaster strikes (CEDIM, 2013). The methodology includes analytical tools from different disciplines (e.g. science, engineering and remote sensing) and merges data from different sources, including crowdsourcing (Prizzia, 2016).

> *The main scientific questions being addressed in CEDIM's Forensic Disaster Analyses are: What are the critical factors that control loss of life, of infrastructure, and of economy? What are the critical interactions between hazard –socio-economic systems – technological systems? What were the protective measures and to what extent did they work? Can we predict patterns of losses and socio-economic*

> *implications for future extreme events from simple parameters: hazard parameters, historical records, socio-economic conditions? Can we predict implications for recovery and rebuilding from these parameters?* (CEDIM, 2013: 9)

Furthermore, some current applications of FDA (i.e. 2011 Tohoku earthquake in Japan, 2011 Thailand flood and 2012 Hurricane Sandy) focused also on shelter needs, business interruption and social vulnerability to disasters (Prizzia, 2016).

3.1.5 Quasi-Judicial Inquiries in Australia

Over 50 quasi-judicial inquiries were performed in Australia in the past 75 years, focused on extreme events such as fires, floods, cyclones and other emergencies (Eburn & Dovers, 2015). These are post-event reviews that can be taken at different levels of government (e.g. departmental inquiries, Ministerial, Parliamentary inquiries). A Royal Commission is "the most significant, prestigious, and independent option open to government (…) to inquire into specified matters" (Eburn & Dovers, 2015: 496). These are non-systematic post-event reviews that have been mainly used for identifying responsibility rather than for learning from past events or disasters, even though in its origins they were also performed for informing policy development (ibid.). Eburn and Dovers (2015) list the short-comings of this quasi-judicial process in identifying how to prevent future events and suggest that a new approach is needed for post-event reviews in order to learn lessons to prevent future disasters.

3.1.6 Incident Investigation Techniques (Root Cause Analysis)

Besides the very specific methodologies and frameworks to analyse the causes of disasters that result from natural hazards, there are other more general investigative methods that can be applied to different types of events and which some have already been applied to the analysis of disasters due to natural hazards. These are generally used to investigate different types of incidents and technological accidents (e.g. accidents in chemical or nuclear plants, manufactural facilities and aeroplane crashes).

These techniques were developed particularly for addressing accidents at work, in the field of safety management. They help to describe what happened, how it happened and why. According to the Guidelines for Safety Investigations of Accidents by the European Safety Reliability and Data Association (ESReDA, 2009), the main phases of accident investigation consist of:

- Data collection;
- Hypothesis generation;
- Analysis;
- Findings;
- Recommendations.

Connections between these phases are not a linear process, but an iterative one (Figure 3) (ESReDA, 2009). Assumptions generated based on the collected data are then tested during the analysis phase. Results can lead to the need for new hypothesis generation. Likewise, created assumptions can lead to other data that needs to be collected. Moreover, the analyst's initial a priori knowledge also shapes the investigation (ESReDA, 2009).

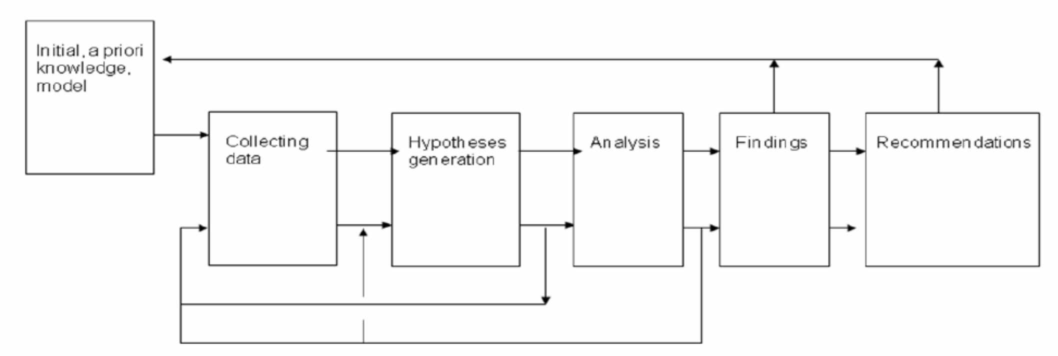


Figure 3 Initial knowledge and accident investigation (source: ESReDA, 2009).

The result of the analysis phase is a set of "proven" hypothesis (i.e. valid hypothesis) that represent the direct and root causes of the accident (ESReDA, 2009). Findings include these results as well as phenomena that were exposed during the investigation but that did not play a role in the accident itself (ibid.).

According to Livingston et al. (2001), there are three key components in an effective incident investigation:

1. A method for obtaining a full description of the sequence of events that led to the failure.
2. A method for identifying critical events and actions (direct causes of the incident).
3. A method for root cause analysis (identification of underlying or root causes).

The overall objective of identifying root causes of accidents is to propose more effective "remedial actions" (ibid.). There are a variety of tools and methods that can be used in each of the previously defined steps, some of which will be described next, following the literature review by Livingston et al. (2001).

3.1.6.1 Sequence Diagrams

These diagrams are used to support the first step of the incident investigation, that is the full description of the sequence of events that led to the failure. It is necessary to define first the end event of the sequence and then to move back to arrive at the incident's start event, generally not known in the beginning but becoming apparent during the investigation (Livingston et al., 2001). The diagram is useful to identify gaps in information between events, which should be collected and used to update the diagram. Examples of sequence diagrams or charts include "Events and Causal Factors charting", "Multilinear Events Sequencing (MES)" and "Sequentially Timed Events Plotting (STEP)" (ibid.).

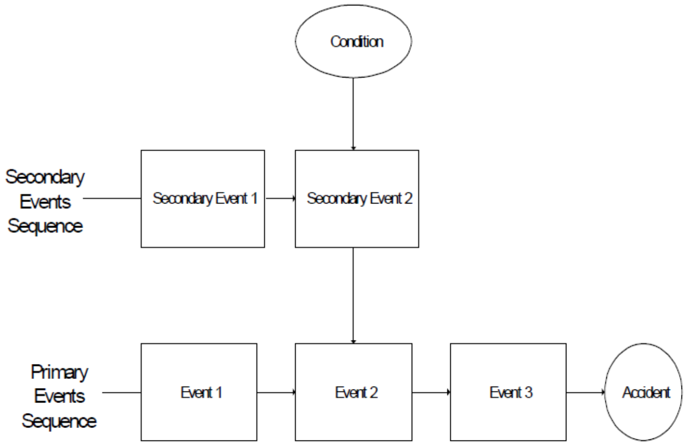


Figure 4 Generic structure of an Events and Causal Factors chart (source: Livingston et al., 2001)

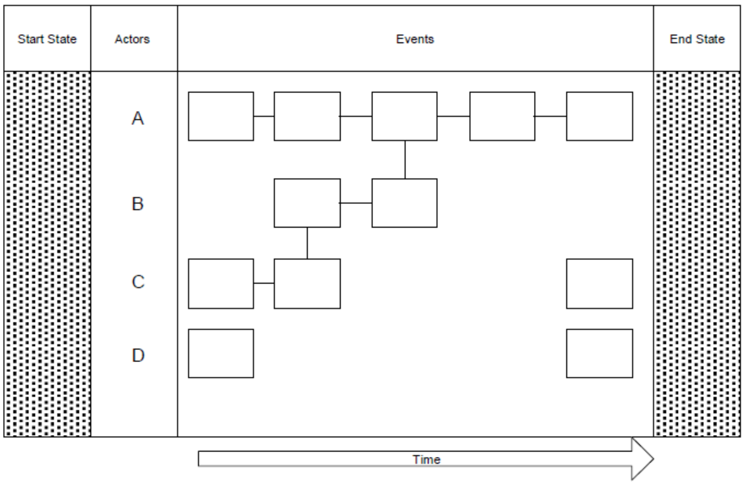


Figure 5 Schematic representation of a STEP (source: Livingston et al., 2001)

Events and Causal Factors charts distinguish between primary events sequence and secondary events sequence, including the associated conditions. The difference introduced by both MES and STEP is the inclusion of all the "actors" involved: actors can be either persons or objects such as equipment or chemical substances (Livingston et al., 2001).

3.1.6.2 Identification of Critical Events and Actions

As suggested by Livingston et al., methods for identifying critical events or direct causes *"act as a filter to reduce the number of direct causes to which further analysis methodologies will be applied"* (2001: 13). Methodologies include: "Barrier Analysis", "Change Analysis" and "Fault Tree Analysis". The attention will be addressed to the description of the Fault Tree Analysis and Barrier Analysis, given that some applications already exist in the field of natural hazards.

3.1.6.3 Fault Tree Analysis

Fault Tree Analysis originated in the Bell Telephone Laboratories in the early 1960s to evaluate safety in the Minuteman Missile Launch Control System (Noon, 2009). It has been applied to analyse the hurricane Katrina disaster (Labib and Read, 2015) and identifying its causes. A fault tree is a logical diagram that shows the interactions of failure events which lead to a specific undesirable event (in this case the disaster); it is built downwards from the undesired event to basic events using logical AND/OR gates and deductive logic (i.e. repeatedly asking 'what are the reasons for this event?') (Labib and Read, 2015).

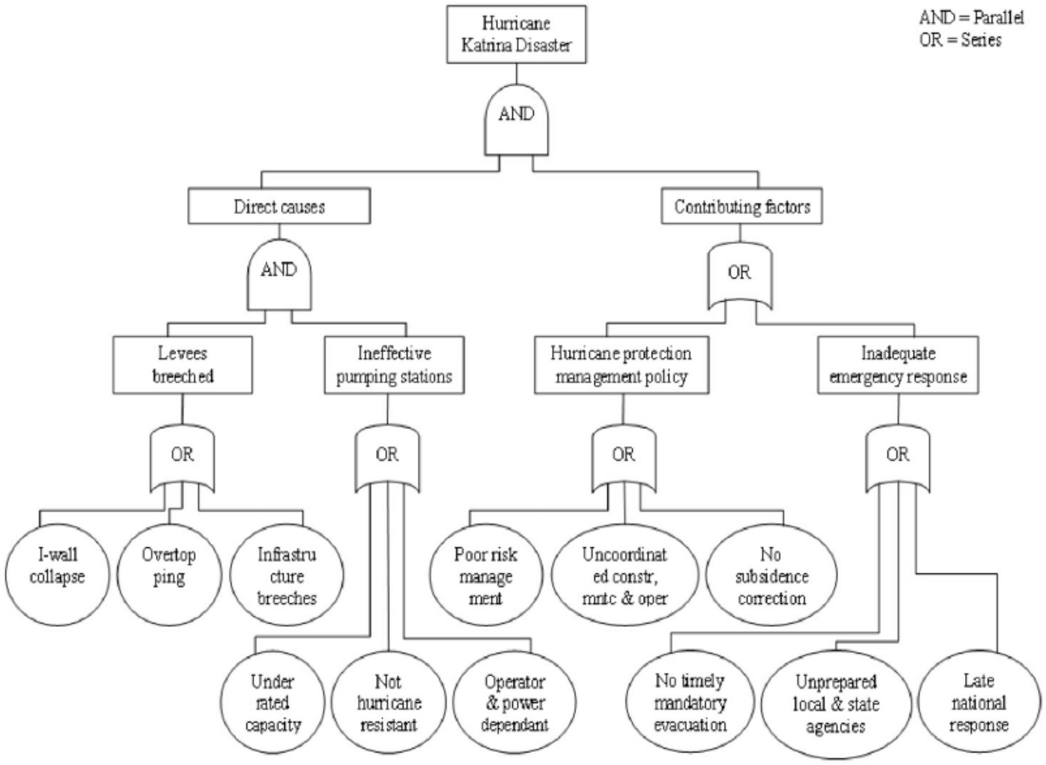


Figure 6 Fault Tree Analysis (FTA) of the Hurricane Katrina disaster (source: Labib & Read, 2015)

3.1.6.4 Barrier Analysis

Barrier analysis is based on three main concepts: "energy", "target" and "barrier". "Energy" represents *"the harmful agent that threatens or actually damages a 'target' that is exposed to it. 'Targets' can be people, things or processes – anything, in fact, that should be protected…"* (Santos-Reyes et al, 2010: 1354). According to this approach, a "barrier" must be put in place between the "energy" source and the "target" in order to prevent an accident from happening (Livingston et al., 2001). The "barrier" concept represents any type of preventative measure, including physical objects (e.g. protective equipment and failsafe systems) and measures such as emergency plans, training and risk assessments (ibid.). The three concepts (i.e. energy, target and barrier) must be investigated, focusing on energy transfers and barrier failures, and generally, require repeating the analysis to find more than one cause of the accident. Five questions must be answered when applying a barrier analysis:

- *"What physical, natural, human action, and/or administrative controls are in place as barriers to prevent this accident?*
- *Where in the sequence of events would these barriers prevent this accident?*
- *Which barriers failed?*
- *Which barriers succeeded?*
- *Are there any other physical, natural, human action, and/or administrative controls that might have prevented this accident if they had been in place?"* (Paradies et al., (1993), as quoted by Livingston et al., 2001)

The Management Oversight Risk Tree (MORT) technique has made barrier analysis more "systematic" and "formalised", by transforming it in a tree structure (Livingston et al., 2001).

Barrier Analysis has been applied by J. Santos-Reyes et al. (2010) to the case of the 2007 Tabasco flood in order to identify a clear set of episodes in preparation for the Management Oversight Risk Tree (MORT) technique. In fact, the first step of the analysis was to describe the sequence of the main events as "thought", then to apply Barrier Analysis to identify "key episodes" or "critical events" and, last, to apply MORT technique for root cause identification. In the application of Barrier Analysis to the Tabasco flood case study, the flooding was represented with the "energy" concept and the "targets" were the affected items, systems and the population.

3.1.6.5 Root Cause Identification

Root cause identification can be achieved using different methodologies, which are mainly characterised as "tree techniques" and "checklist methods" (Livingston et al., 2001). Tree techniques are in the majority prescriptive (e.g. Management Oversight and Risk Tree (MORT) and Human Performance Investigation Process (HPIP)), which means that they list possible root causes that the analyst needs to consider (ibid.). Checklist tools simply require ticking categories in boxes and include methodologies that can be used by a single analyst and some that require a group of people to be conducted (similarly to the case of CTM) (Livingston et al., 2001).

An example of application of root cause analysis methods in the disaster field is the use of a technique (Ideation Failure Analysis™) originally designed to find the root cause of a manufacturing failure, to avoid the problem of cascading failure in a city's critical infrastructure when a natural disaster occurs (Taylor, 2016). In-depth expert knowledge on possible failures and cascading effects is needed throughout the whole process, which is hierarchically developed in several steps. The application of the method requires a great effort in terms of time and resources, also considering that several expert teams are needed because the problem is divided into several individual parts (Taylor, 2006).

3.1.6.6 Causal Tree Method (CTM)

Causal Tree Method is based on the hypothesis that an incident results from changes in the normal process (Livingston et al., 2001). Unlike Fault Tree Analysis, it only includes the tree branches that led to the accident (i.e. not 'OR' gates but only 'AND' gates) and it requires to be undertaken by a group, including involved actors and an expert analyst in CTM (ibid.). Just like in FTA, the end event is the starting point of the analysis, working backwards by asking three questions (Livingston et al., 2001: 28-29):

1. "What is the cause of this result?"
2. "What was directly *necessary* to cause the end result?"
3. "Are these factors (identified from 2) *sufficient* to have caused the result?"

Consensus must be reached by all members of the group when moving backwards at each step and a minimum of 3 factors need to be identified (classified as organisational, human and material factors) (ibid.).

3.1.6.7 Management Oversight Risk Tree (MORT)

The Management Oversight Risk Tree (MORT) technique is "a comprehensive, analytical procedure that provides a disciplined method for determining the causes and contributing factors of major incidents" (Livingston et al., 2001: 20). MORT's chart represents a tree, as in Fault Tree Analysis (FTA), the difference being that this tree is already constructed, so the analyst does not need to build it but to go over an existing chart and remove non-relevant branches (ibid.). In addition, as opposed to FTA, MORT also investigates causal factors.

The basic MORT structure contains a top event ("losses, injuries, damage, etc.") and beneath two main sub-branches ("alternative causes", separated by the OR logic gate) that are labelled "oversight and omissions" and "assumed risks" (Santos-Reyes et al., 2010). The first step is to determine the facts regarding the top event (e.g. what happened, why and what were the losses) (Livingston et al., 2001). By default, unknown and unanalysed risks belong to the "oversight and omissions" branch; only identified and analysed risks can be positioned in the "assumed risks" branch, given that they were accepted at the appropriate management level (Livingston et al., 2001). The "oversights and omissions" branch contains the "what happened?" and the "why it happened?" sub-branches, under an AND logic gate; the process consists on completing the "What happened?" branch and then the "why" branch, which contains the causes, by answering to specific predetermined questions in the user manual (Santos-Reyes et al., 2010). "The 'what happened' considers the specific control factors that should have been in operation while the 'why' considers general management system factors" (Livingston et al., 2001: 21).

The analysis is developed by going over the entire tree to find the basic causes that have contributed to the top event, with time implicitly included, through factors at the bottom left occurring earlier than those on the top and right side of the tree (ibid.). Factors are evaluated in terms of their adequacy (criteria for the evaluation is defined in the user's manual): "less than adequate" factors are coloured in red, "adequate" factors in green and those that require more investigation for their evaluation are coloured in blue. The objective is to find the missing information in order to avoid having issues or branches coloured in blue. The Management Oversight Risk Tree (MORT) technique was applied to the case of the Tabasco flood disaster in 2007 by Santos-Reyes et al. The authors state that this technique was selected for the analysis because "it has been considered to be a relatively simple checklist approach to causal analysis" (2010: 1355). After the application of MORT, the analytical technique proposed by Briscoe (as quoted by Santos-Reyes et al., 2010: 1359) was used to differentiate between root causes and other general causal factors, which provides different main categories for the identification of root causes (i.e. policy, policy implementation, bridge elements and risk assessment). Causal factors identified in the Tabasco flood were all classified under the "hazard analysis process" root cause: "This may be regarded as one of the key lessons of the present analysis; i.e., the approach to decision making in relation to 'flood management' at the time of the disaster was not based explicitly on a 'flood risk assessment' approach" (Santos-Reyes et al., 2010: 1359).

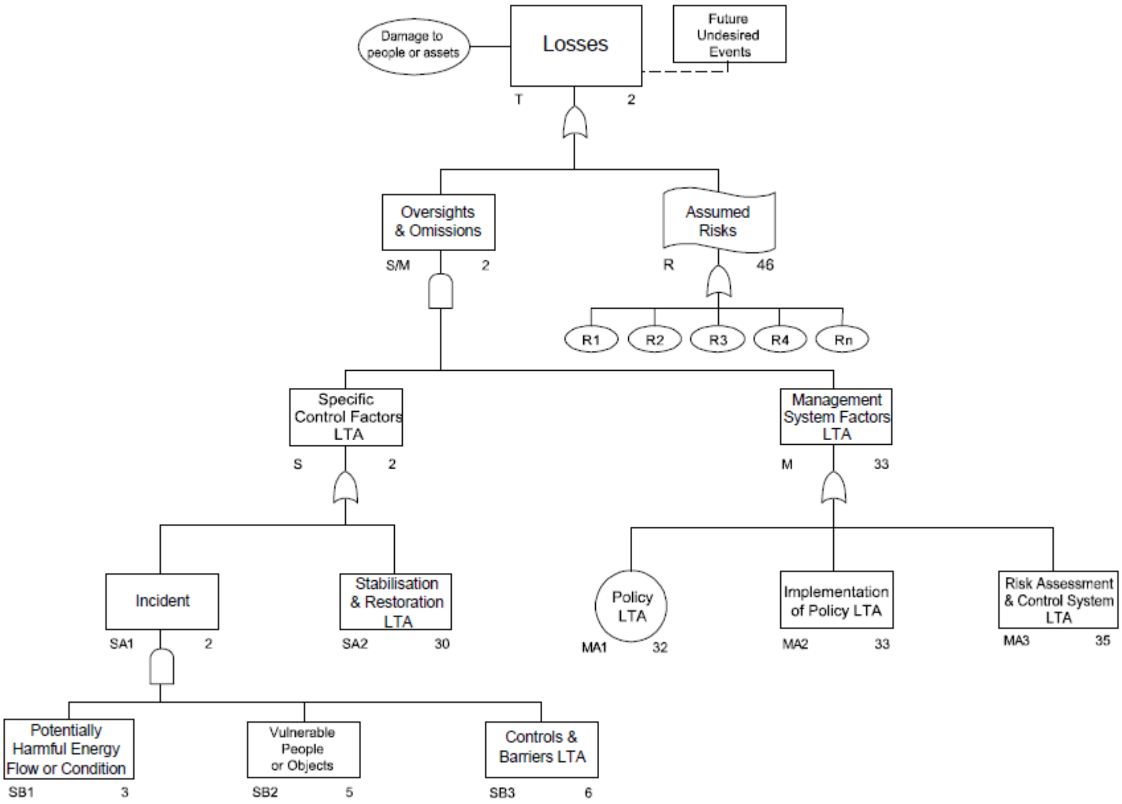


Figure 7 Generic MORT tree structure (source: NRI-1, 2002)

3.1.7 Summary of Approaches for Disaster Forensic Investigation

The literature review on existing forensic methods shows that approaches designed specifically for analysing disasters are at the beginning of their development. The process that needs to be followed to perform a disaster forensic investigation is not clearly defined in most of the revised methods. The data that are required for the analysis is never mentioned and, except for the methods from forensic engineering, neither are the tools for data analysis. Table 7 provides a summary of the main aspects of some of the methods presented above. The table includes a list of input data as well as data sources that were identified from the study of available documents. In some cases, it was not possible to individuate some of the aspects and so they were left blank.

Table 7 Disaster forensic investigation approaches (source: author).

Approach name	**Key author**	**Year**	**Area of application**	**Objective**	**Case study applications**	**Characteristics**	**Methodology**	**Tools and methods**	**Data representations**	**Input data**	**Data sources**	**Output data**	**Output format**
Forensic Engineering: environmental case histories	G. Shiurman & J. E. Slosson	1992	Environmentally related failures and disasters	Discovering the causes of accidents and environmentally related failures and disasters, mostly for legal purposes but not only.	Flooding (Tia Juana river 1980, San Fernando Valley 1980, Southern California 1977), land subsidence (Alviso 1983), landslides (Malibu 1983, Utah 1983, Abalone 1986), erosion, sediment deposition and land movement (Russian River).	Disaster recreation step by step, chronologically.	Desk review, informal interviews, field inspection.	Geologic investigation, hydrologic studies/hydraulic modelling, comparative analysis of damages.	Chronologic list of all events in connection of the disaster.	Mean annual rainfall, dates and discharges of historic floods, flood return frequencies, event hydrograph and return period, geologic/geomorphology data, hydraulic infrastructure data (geometry, design charact., operation), Number and location of damaged items.	Media documents, videos, stories, photographs, reports, eyewitness reports, aerial photographs, Historic topographic maps, construction contract documents.	Chronologic recreation of the disaster, reasons why it occurred, how it could have been prevented and what should have been learned in terms of future planning, design and public policy.	Case histories: description of the event, the investigation, the litigation, the post-mortem.
Forensic flood hydrology	H. Loaiciga	2001	Floods	Determining probable causes and sources of human-induced contributions to flood damages.	San Luis Obispo Creek of California.	Approach that integrates climatic, hydrologic, and hydraulic principles and models to discern the probable causes of flood damage in a basin that undergoes flood-plain development.	Field observations and measurements	Hydraulic analysis of floods, hydraulic modelling		Rainfall depth, Precipitation Depth-Frequency Relationships, tide levels, basin area, river geometry and cross sections, flood-plain changes (land-use changes, development, uncontrolled vegetation, etc.), geometry of bridges and hydraulic constructions (design), presence of debris and vegetation.		Contribution of each flood factor to change in water level in percentage and absolute change in water level.	Table
Methodological Guide for the Forensic Analysis of Floods	A. I. Ramirez	2015	Forensic hydrology, flood forensics, droughts	Determination of natural and human induced causes that made a natural phenomenon a disaster, for identifying responsibilities but mainly for disaster prevention.	Floods in Tabasco, Mexico		Desk review, interviews, field work	Statistical analysis for hydrology and hydraulics, rain-runoff and hydraulic modelling, factors matrix	Hazard maps	Rainfall depth, measured river flows, water elevation, velocity, sediment transport, existing hydraulic infrastructure (design return period, location, geometry, etc.) and related operational programs, development plans and programs, land-use plans, historic land-use maps (land-use changes), socio-economic information on the population, garbage disposal practices, damages (physical and in monetary terms), emergency management plans and programs, early warning system, measures taken, prevention/alert actions,	Flood hazard maps, Geographic data (thematic maps), satellite images, aerial photographs, topographical assessment, indirect personal testimonies of involved stakeholders, technical reports and media documents regarding past events,	Technical factors (hydrometeorologic, hydrologic and hydraulic) and social and economic dimensions, ranked according to their level of failure and causality.	Factors matrix, Summary of causes and effects, lessons learnt, recommendations and courses of action.
Forensic Investigations of Disasters (FORIN)	O. Smith, Integrated Research on Disaster Risk (IRDR)	2010-2016	Natural, "socio-natural" (recognising the influence of human activity on natural hazards) and technological hazard events	Identifying underlying (root) causes in such a way that they can be evaluated and addressed by policy and practice; other specific objectives such as broadening the scope of DRR measures, contributing to an understanding of the ways to incorporate disaster risk reduction into development planning decision-making and economic and social growth.	Typhoon Morakot 2009, geohazard risk associated with the Valley Fault System, Mega Earthquake and Tsunami in Central Japan	Structured around a causal chain, incrementing the analysis in-depth: Descriptive analysis (immediate descriptive causal relations), risk drivers or dynamic processes and root causes.	Selection of specific methodologies depending on the research questions.	Retrospective Longitudinal Analysis (RLA), Disaster Scenario Building (DSB), comparative case analysis, meta-analysis		Data on triggering event(s): Scale, intensity, return period, explanation of the event by press and authorities. Data on exposure of social and environmental elements: spatial distribution of people, infrastructure, production, wealth, natural resources, socio-economic strata, types of infrastructure, housing and critical infrastructure, historic data of exposure, Social and economic structure of exposed communities: distribution of loss, damage and impacts, social groups, post impact relief, resources available for response, existence of insurance, social resilience, vulnerable groups. Data on institutional and governance elements: legislation, insurance, urban and land-use planning, norms, legal provisions, etc. restricting or promoting the location in hazard-prone areas and their obedience, zoning regulations, land use controls, infrastructural codes, insurance legislation.		RLA: historical narrative of risk construction. DSB: scenarios to inform government, civil society and community. Comparative case analysis: understanding of the differential contexts and processes that expose people and their assets to risk. Meta-analysis: patterns or commonalities across and among a wide array of studies.	

Approach name	Key author	Year	Area of application	Objective	Case study applications	Characteristics	Methodology	Tools and methods	Data representations	Input data	Data sources	Output data	Output format
PERC methodology	K. Venkateswaran, Zurich Insurance Group	2015	Disasters due to "natural" and "non-natural hazards"	Uncovering root causes, successes and failures in the management of disaster risk prior to the event, disaster response and post-disaster recovery; identifying critical gaps and actionable opportunities for mitigating disaster risk.	Central European floods 2013, floods in Boulder, Balkan floods 2014, Switzerland floods 2014, floods in Nepal 2014, Morocco floods 2014	The analysis is structured around the disaster risk reduction and management cycle (risk reduction and preparedness, response, recovery).	Desk review, fieldwork, semi-structural and informal interviews		Disaster institutional landscape map, timeline of important events	Disaster duration, location , geography of area, hazard-scape, hydrological/meteorological analysis, data on previous events in the region/location, historical data on exposure (assets in at risk area) and their characteristics, related socio-economic drivers, existing physical protection structures, damages/losses, indirect impacts, existing regulations (e.g. in land-use planning), Preparation and response to previous events by involved actors, data on response activities (rescue, evac., relief), data on post-recovery actions/reconstruction.	Newspaper articles, opinion pieces, peer-review articles, working papers, and reports about the disaster event.	Key insights: successes and critical gaps in prospective risk reduction such as land-use planning, corrective risk reduction, preparedness, response and recovery; recommendations and opportunities for action: focusing on what went wrong but also strengthening what went well, emphasizing prospective risk reduction pathways and avoiding the rebuilding of risk into the system	Structured report
Detecting Disaster Root Causes: A Framework and an Analytic Tool for Practitioners	German Committee for Disaster Reduction (DKKV)	2012	Disasters due to natural hazards	Identifying disaster root causes and defining areas for DRM interventions to address them. The study aims to examine the various context conditions and trends that heavily influence vulnerability, exposure, risk, and DRM.	Haiti earthquake, Indonesia tsunami, Mozambique floods, Pakistan floods, Philippines typhoon.	Analysis of causal linkages between disaster impacts and underlying root causes. The disaster risk management cycle is integrated into the analysis approach.	Desk review, expert interviews	Current reality tree (CRT) or causal tree	Matrix with two key axes: X-Axis describes the pre-disaster condition and the post-disaster activities; Y-Axis shows the progression of analysis level (from drivers to root causes).		Scientific papers, reports produced by institutions, stakeholder reviews and reports, peer-reviewed journals, grey literature, country reports, Post-disaster Needs Assessment (PDNA), Vulnerability and Capacity Assessment (VCA), Real-Time Evaluation (RTE)	Root causes, risk drivers, potential intervention options.	Matrix with causal linkages between drivers and root causes.
Forensic Disaster Analysis in near real time	CEDIM Center for Disaster Management and Risk Reduction Technology c/o Helmholtz Centre Potsdam	2012	Disasters due to natural hazards: geophysical, meteorological and hydrological hazards.	Improving our understanding of how natural hazards do (or do not) become disasters, providing information and results within the first few hours and days of the disaster.	Superstorm Sandy, U.S. Extreme Drought and Record Heat 2012, Tropical Cyclone "Saola", Philippines and Taiwan, Earthquake Sequence, 20th and 29th of May 2012, Ferrara, Italy, Van Earthquake (Eastern Turkey), 23 October 2011.	Focus on near real-time disaster analyses by interdisciplinary teams, complements IRDRs FORIN. Focus on the complex interactions between the natural hazard, the technical installations, facilities, and infrastructures, and the societal structures, institutions and capacities.		Models, methods and tools for data extraction from Twitter, rapid assessment of atmospheric events and floods, rapid assessments of socio-economic impacts, direct and indirect losses, transportation and supply chain interruption.	Hazard maps, damage maps, damage graphs.	Hazard data: hydrometeorological data (evolution in time), intensity, return period, affected areas, secondary hazards. Impacts data (for the event and historic data): fatalities, fatality causes, evacuation and shelter (order and response), electric power outages (number of customers by region), Cost of power outages (historic data), value added of manufacturing sectors located in affected area + days of business interruption, benefits of some industries (reconstruction), transport infrastructure (traffic obstructions and causes).	Twitter (tweets with key words related to disaster)	Near real time event description and estimation of impacts.	Non-systematic report, including hazard description, impacts analysis (casualties, evacuation, indirect losses, outages), sometimes vulnerability/resilience analysis if available from other sources.
Retour d'experience	DDSC (Direction de la Defense et de la Securite Civile), France	2006	Management of Civil Protection emergencies	Focus on emergency management: Learning at the local and national level, event reconstruction, identification of actions taken, construction of scenarios with alternative actions to manage the event better.	Floods, fires, avalanches, explosions.	The main objective of data collection is to reconstruct progressively the "real/actual" history of the event and its management, including the understanding of the context and actors' motivations.	Desk review, interviews, plenary meetings.	Cause-consequence diagram method, fils conducteur.	Graphic representation of timeline with events and decisions, cause-consequence diagram, fils conducteur representation.		All written documents and oral testimonies of the actors involved in the event management, Documents available in the departments and agencies concerned, published press articles, photos and audiovisual reports, visits and observations on the site(s) concerned, conclusion statements, interviews with some event managers.	Chronologic recreation of the event with decisions taken, event causes and barriers/protections put in place, event recreation as a succession of decisions taken and hypothetical/alternative decisions (positive and negative).	Report: the event record and summary note, the chronogram of the event and its management, the cause-effect diagram, the fils conducteur(s), decision cycles, the synthesis of the issues and problems and the action plan.
Methodologie de retour d'experience des actions des gestion des risques	J. L. Wybo	2003	Environmental crisis and accidents management	Identification of failures and related solutions, knowledge production and learning.	Erika naufrage crisis in Belle-Ile-en-Mer, France.	It is based on the individual and collective experience of actors involved in the crisis.	Desk review, individual interviews, meetings with actors	Decision/ hypothetical/ event cycles	Graphic representation of timeline, "cards" for decision cycles, fils conducteurs.		Reports, documents available in involved organizations, media documents, internal DBs and interviews with different actors.	The common history of the development of the crisis and management, as it really happened, supplemented by all the alternative hypotheses envisaged by the actors.	Case study report with collective event, fil conducteur, decision cycles and proposed actions.

3.2 DAMAGE TYPOLOGIES

The 2014 EU report by De Groeve et al. called to overcome the differentiated terminology for damage classification and types of loss indicators by proposing to set standards for data sharing between the Member States. However, concerning the elementary damage data categories, there is still a large lack of clarity in the literature and in the frameworks themselves.

It is agreed that when dealing with damage data, it has to describe the impact of a disaster in terms of the quantity of damage that affects people, objects and systems. However, damage related terms often overlap and are not unique. For example, Gall et al. (2014) explain that the terms "loss" and "damage" are generally interchangeably used to describe the impacts of disasters. However, sometimes "loss" is used to represent market-based negative economic impacts, quantifiable measures that can be expressed in monetary terms (NRC, 1999, as quoted by de Groeve et al., 2014), while "damage" lacks quantitative characteristics, but may be measured and expressed as a loss (Gall et al., 2014).

Furthermore, damages may be classified as direct/indirect and tangible/intangible (Hubert et al., 1999, Merz et al., 2010, Gall et al., 2014). Direct damage refers to the immediate physical impact caused by the disaster, for example in the case of floods they result from physical contact of water with humans or objects (Merz et al., 2010). Indirect damages have different definitions, such as the "subsequent or secondary results of the initial destruction" (Gall et al., 2014: p.3) or damage induced by direct damages and that occur outside the flood event, in space or time (Merz et al., 2010). Additionally, under the term "indirect" damages or losses it is possible to find many different impacts such as economic losses due to lost revenue and business interruption, lost income to societal losses, environmental damage (Gall et al., 2009), cleaning costs, costs of service disruption, psychological effects, long-term health impacts, etc. (Hubert et al., 1999).

Moreover, both direct and indirect damages are further classified as tangible or intangible. Tangible damages refer to effects that can be evaluated in monetary values, while intangibles are damages that are difficult to express in monetary terms (Hubert et al., 1999). Tangible damages are damage to goods or services that have a market, and thus, can be easily transferred in monetary terms, while intangible damage is damage that cannot be easily expressed in monetary values because it involves goods and services which are not traded in a market (non-market values) (Merz et al., 2010, Meyer et al., 2013).

3.3 DISASTER DAMAGE DATA COLLECTION IN POLICIES

A general interest arose in the last years to define and regulate damage data collection processes in order to properly support policy makers and decision makers for Disaster Risk Reduction (DRR) and to improve disaster response policies and mechanisms. Several frameworks and policies at different levels call for the systematic assessment and record of disaster damages and losses for multiple purposes.

DRR policies have set different objectives that need to be supported by the use of disaster damage and loss data. Until recently, these damage data usages and applications were not analysed and distinguished clearly; however, there has been growing reflection and awareness on how such data are essential and useful to support different DRR policies (see JRC expert working group, De Groeve et al., 2013, 2014, 2015 and Marín Ferrer et al.

2018; DATA Project by IRDR, 2014 and 2015). Likewise, international as well as European DRR policies explicitly require disaster damage and loss data collection and the implementation of databases to organise and store systematically these data. For instance, at the international level, the Sendai Framework for DRR 2015-2030 outlines among UNISDR strategic outputs the development and improvement of national disaster damage and loss databases (UNISDR, 2015b). At a European level, the Floods Directive (Directive 2007/60/EC) asked member states to start collecting data for significant flood events occurred from December 2011 (EC, 2013a).

Several international policies dealing with DRR and risk management have proposed guidelines to normalize the process of damage data collection by suggesting frameworks for the definition of the activities that should be performed, the stakeholders to be involved, the damage data categories and their respective formats, etc. Some of these DRR policies are already being supported by existing disaster damage and loss databases. For instance, DesInventar Sendai is a new version of DesInventar, a conceptual and methodological tool for the construction of national disaster damage and loss databases, set by the UNISDR to support the Sendai Framework (UNISDR, 2018).

On the other side, in the last years, we have assisted to wide-ranging post-disaster damage and loss assessments carried out by academia, the private sector, governments or international organisations all over the world (OECD, 2014). Even when these damage and loss data are stored in national databases (De Groeve et al. 2014) their formats and the way they were collected makes comparisons across events and countries very challenging (OECD, 2014).

Three international frameworks were selected and reviewed next, namely, Sendai Framework for Disaster Risk Reduction, OECD Disaster Risk Management Expenditure Framework and EU JRC recommendations and guidelines. First, each framework is explored through the range of damage and loss data collection objectives. Second, the different data usages and applications that are associated with these objectives are identified. Last, damage data spatial/temporal scales and categories are defined from selected policies. Results are presented in Table 8.

Both the Sendai and OECD frameworks require damage and loss data mostly for monitoring and evaluating DRR policies through different types of accounting. However, while Sendai's approach aims at aggregating all-encompassing losses and damages (i.e., aggregating all losses of all events at a national level annually), OECD calls to aggregate specifically the disaster-related costs, which include socio-economic losses due to disasters and risk management expenditure (i.e., at the national level and annually). In contrast, the JRC recognized different data application areas or usages of national interest (i.e., disaster loss accounting, disaster forensics, risk modelling and disaster loss compensation), by considering not only how damage and loss data are used at a policy level but also how other relevant stakeholders, such as researchers and practitioners, use them. In addition, the EU aims through the JRC recommendations and guidelines firstly to define a mechanism to record systematically the losses in the European territory, and secondly, to supply European loss data to international initiatives at providing global loss trends (De Groeve et al., 2013).

Table 8 Review of main international policies: damage data collection objectives, usages, scales and data categories (source: author).

DRR Framework	**Damage data collection objectives**	**Damage data usages and applications**	**Spatial scale of damage data**	**Temporal scale of damage data**	**Damage Data categories**
The Sendai Framework for Disaster Risk Reduction 2015 – 2030	- Monitoring and reporting of States progress in (i) achieving a substantial reduction of disaster risk and losses and (ii) preventing new and reducing existing disaster risk - Capture progress in the prevention of new, and the reduction of existing risk, and the strengthening of the resilience of persons, businesses, communities and countries. - Adjust the disaster risk reduction national policies. - Application of disaster-related data in policy and investment decision-making and action.	- Quantitative measurement of indicators describing on a national basis the damages occurring to people's lives, livelihoods and health and to the economic, physical, social, cultural and environmental assets of persons, businesses and communities. - Understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment.	- Loss reporting on a national level	Annual basis reporting	- Human losses expressed as the number of affected people (death, missing, injured, etc.) - Number of damaged objects - Damage expressed as costs ("economic losses") - Number of disruptions.
The OECD public and private Disaster Risk Management (DRM) expenditure framework	- Assessing risk reduction-related public and private spending. - Better understanding of how much countries spend ex-ante in risk reduction. - Better understanding of how much countries spend ex-post in disaster management and rehabilitation.	- Evaluation of the economic benefits from disaster risk investments.	- Loss recording on a local level - Loss reporting on a national level	- Annual basis (i.e., fiscal year)	- Social losses (i.e., number of deaths, missing and affected people) - Economic damage expressed as different categories of costs (i.e., direct tangible cost, loss due to business interruption, indirect cost and intangible cost)

DRR Framework	**Damage data collection objectives**	**Damage data usages and applications**	**Spatial scale of damage data**	**Temporal scale of damage data**	**Damage Data categories**
EU JRC Guidance for Recording and Sharing Disaster Damage and Loss Data	- Supporting the EU disaster prevention policy making. - Supporting evidence-based disaster risk management policies and actions. - Implementation of disaster risk reduction strategies in Europe (from local to national scales). - Sharing loss data across organisations, among the EU Member States and with EU and international institutions	- Local and regional disaster risk assessment. - Disaster loss accounting. - Disaster forensic investigation. - Risk modelling - Compensation.	- Loss recording on a local level -Loss reporting on a national level	- Annual basis	-Standardized hazard event identification - Affected elements by sector (i.e., social people), economic (property, infrastructure, economic activity), environment and heritage) - Damage and loss indicators by sector including human loss indicators, damage indicators and economic loss indicators which are divided into direct losses, indirect losses and intangible costs
EU Floods Directive	Supporting the selection of flood risk management measures.	Preliminary Flood Risk Assessment. Flood risk assessment.	- River basin district, unit of management or the portion of an international river basin district.	- Event-based.	- Flood event: flood extent. - Impacts on human health, the environment, cultural heritage and economic activity.

3.3.1 The Sendai Framework for DRR

The Sendai Framework for Disaster Risk Reduction 2015 – 2030 called to the systematic and cyclical measurement, monitoring and reporting of States progress in (i) achieving a substantial reduction of disaster risk and losses and (ii) preventing new and reducing existing disaster risk (UNISDR, 2015b). The monitoring process proposed by Sendai is mainly based on quantitative measurement of indicators describing on a national basis the damages occurring to people's lives, livelihoods and health and to the economic, physical, social, cultural and environmental assets of persons, businesses and communities. These indicators, defined to describe seven global targets on the progress of disaster losses reduction, require the collection of data on impacts to the population (mortality and affected people), economic losses, damage to critical infrastructure and disruption of basic services.

In order to fulfil the Sendai Framework requirements and assess the requested indicators, damage and loss data should be collected and reported on an annual basis by the States who committed to the agreement by March 2019. As presented in Table 8, the Sendai Framework encourages States at using disaster damage and data to monitor, adjust and apply DRR policies.

The different data categories required for the calculation of the Sendai indicators were identified and reported in Table 8. The very recent "Technical Guidance for Monitoring and Reporting on Progress in Achieving the Global Targets of the Sendai Framework for Disaster Risk Reduction" (UNISDR, 2017d) provides for each global target the applicable definitions and terminology and defines for each indicator the minimum data requirements as well as their desirable disaggregation. Specifically, indicators from global targets A and B require data on deaths, missing persons and affected people (i.e., injured/ill and people with destroyed/damaged or disrupted houses and livelihoods). Target C instead requires data on economic losses of different sectors (i.e., agriculture, other economic sectors, housing, critical infrastructure and cultural heritage). Last, global target D on damage to critical infrastructure and disruption of basic services requires the number of destroyed or damaged facilities and units (health, educational and critical infrastructure) and the number of disruptions to different services (educational, health and other basic services). Global targets E, F and G do not require damage and loss data in their computations and are therefore out of scope.

3.3.2 OECD Disaster Risk Management expenditure framework

The Organisation for Economic Co-operation and Development (OECD) issued in 2014 the Public and Private Disaster Risk Management (DRM) expenditure framework to support policymakers to track more systematically whether their spending efforts actually lead to future reductions in impacts suffered from disasters (OECD, 2014). The OECD framework aims to respond to the need to understand how much is spent ex-ante for prevention and reduction of negative impacts of disasters and ex-post in response and recovery from disasters. The OECD requires both public and private spending in Disaster Risk Management to be assessed (by governments, citizens, private sector).

The review of international and national disaster losses data collection methods on a set of selected OECD countries and existing international damage and loss databases shows that practically none of them has comprehensive cost assessments (OECD, 2014). Cost categories such as direct losses, business interruption and indirect losses are usually taken into account, while reconstruction and recovery costs and the costs of planning and implementation of risk prevention measures are hardly considered (ibid.).

Table 8 shows that the main OECD framework objectives regarding disaster damage data collection concern the evaluation of investments across different sectors (both private, public) and phases of the DRR cycle (i.e., prevention/mitigation, preparedness, emergency response and recovery/reconstruction) through the evaluation of the economic benefits of disaster risk reduction investments. Indeed, the accounting of both disaster socio-economic losses and public expenditures in DRR provides evidence on the effectiveness of DRR measures and policies (OECD, 2016).

Concerning damage data categories, the OECD expenditure framework (2014) considers two disaster cost components, i.e., disaster socio-economic losses and public and private expenditures for disaster risk management. Disaster losses include damage data describing social losses (i.e., number of deaths, missing and affected people) and damage expressed as different cost categories (i.e., direct tangible cost, loss due to business interruption, indirect cost and intangible cost). The OECD recommends damage data to be collected at a local level according to predefined national guidelines and then aggregated and reported at the national level (i.e., loss data has to be submitted to the national government for monetarization, aggregation and publishing).

Public and private expenditure in Disaster Risk Management (DRM) is broken down into the following costs: staff costs, administrative costs, overheads, capital investment, operations & maintenance, and other. The proposed Framework aims to obtain DRM expenditure information triangulating it according to these categories: (i) The phase in the DRM cycle (i.e., Risk Prevention and Mitigation, Preparedness, Emergency Response, Rehabilitation and Reconstruction); (ii) the subject that sustained the cost (i.e., Ministry/Department, National/Subnational or other [such as EU], Private [households or businesses]); And (iii) the hazard type according to the disastrous event (i.e., Natural or Man-made).

3.3.3 EU JRC Guidance for Recording and Sharing Disaster Damage and Loss Data

In 2013, the Directorate General Joint Research Centre was tasked by the EU commission to create an expert working group with members from the EU Member States to report on the current state of the art in Europe and recommend best practices and guidelines on disaster damage data collection (De Groeve, 2014). The first recommendations were issued in 2013 (De Groeve et al.) and provided technical requirements for an EU approach for a loss data model, derived from the needs in three application areas: disaster loss accounting, disaster forensics and risk modelling. An additional data application area related to loss compensation purposes was added in the following report by De Groeve et al. (2014). These different data application areas or usages were identified considering how damage and loss data are used for policymaking and how a broader range of stakeholders uses these data. Subsequent reports focused on the state of the art and best practices for recording disaster loss data in EU member states (De Groeve et al. 2014) and on developing and proposing a minimum set of loss indicators for sharing loss data across organisations, among EU Member States and with EU and international institutions (De Groeve et al. 2015).

As presented in Table 8, the main objectives of the JRC recommendations and guidance with respect to damage data collection and reporting concern European DRR policy-making and implementation at different levels. In fact, some identified data usages, such as risk assessment and disaster forensic analysis, are used (and useful) to support DRR actions.

To support the data application areas that the JRC defined, De Groeve et al. (2013) recommend collecting and recording the following data categories: Hazard event identification, affected elements and loss indicators describing damage/loss of affected elements. Affected elements include people, property and the environment; property considers both immovable (buildings and civil works) and movable property (contents, vehicles, products). Considered damage and loss categories are direct damage to exposed elements, indirect loss/damage and total loss/damage. The guidelines recommend the recording of damages at a local level (i.e. at the asset and municipal levels) and aggregation of damages and losses from asset to sector level based on the hierarchical classification of affected elements (De Groeve et al. 2013). The asset level should support both disaster forensics and risk modelling (with the georeferentiation of affected elements), while the municipal level, organized by sectors, is required for loss accounting (De Groeve et al. 2013).

3.3.4 The EU Floods Directive

The European Directive 2007/60/EC ("Floods Directive") on the assessment and management of flood risks, requires the Member States to develop Flood Risk Management Plans. The aim of the Floods Directive is to establish a framework for measures to reduce the risks of flood damages, to human health, the environment, cultural heritage and economic activity. The selection of flood risk management measures must be based on the knowledge from both flood hazard and flood risk maps. Therefore, the Floods Directive requires the development of flood risk assessments, including preliminary flood risk assessments based on data on past flood events for each river basin district, a unit of management or the portion of an international river basin district or unit of management lying within their territory.

The Directive requests to describe past floods of significant adverse impacts on human health, the environment, cultural heritage and economic activity, including their flood extent and the assessment of the impacts. It was recognised that not all of the data requested for past events are available, so member states were asked to start collecting these data for significant flood events that occur after 22 December 2011.

3.4 POST-FLOOD DAMAGE DATA CATEGORIES REQUIRED FOR FORENSIC INVESTIGATION

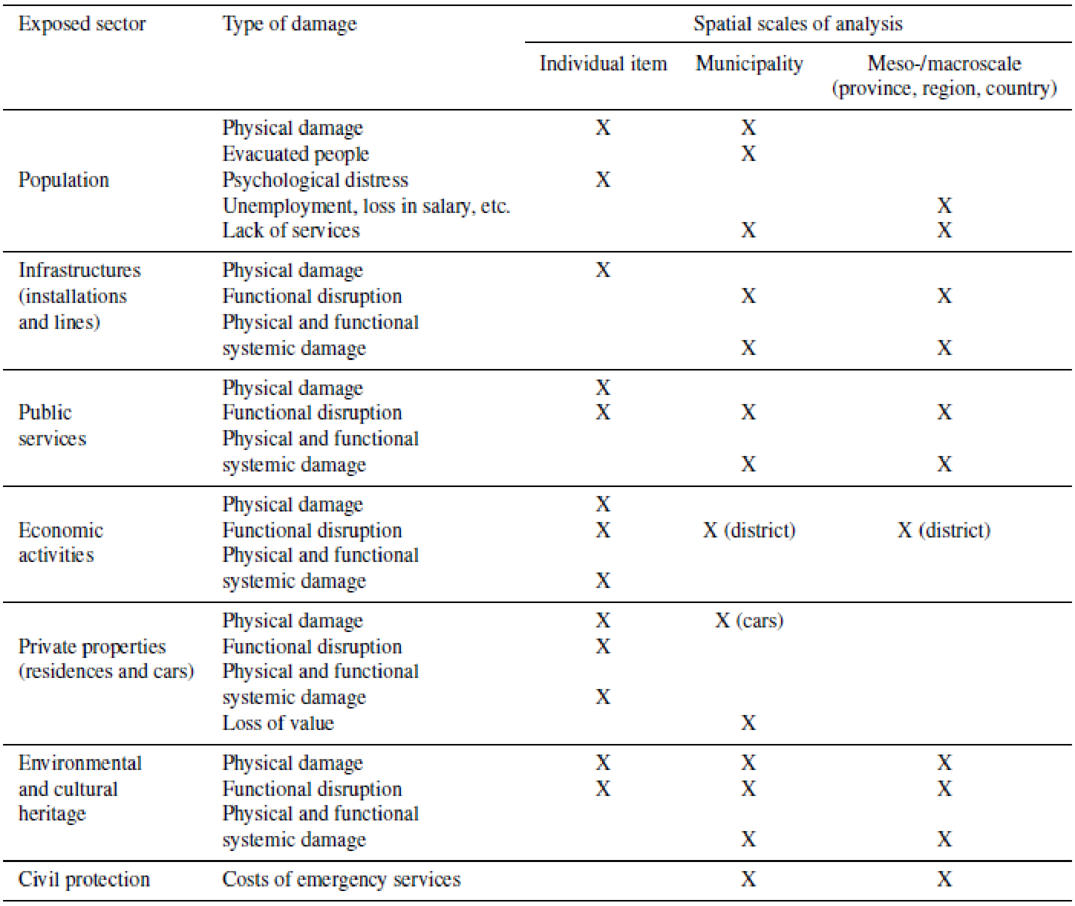
The policy review is complemented by considering data categories that emerge from post-flood damage assessment methodologies. The post-flood damage assessment model by Menoni et al. (2016: pp.2783) calls for an assessment that has to "(i) be multisectoral, (ii) consider physical, functional and systemic damage, (iii) address the spatial scales that are relevant for the event at stake depending on the type of damage that has to be analysed (i.e., direct, functional and systemic) and (iv) consider the temporal evolution of damage". The main logical axes of the model are the exposed sectors, the types of damage and the spatial scale (Table 9).

Firstly, a "multisectoral" damage assessment means assessing the impacts on all affected sectors (i.e. people, critical services and infrastructures, economic activities, residential buildings, cars, the environment and cultural heritage), including the costs of emergency management, which can represent a significant share of the total costs (Menoni et al., 2016). This systemic perspective on the damage to multiple sectors allows as well the consideration of interdependencies and interrelations among sectors leading to indirect damage, determined by ripple, cascading, and enchained effects.

Secondly, the classes of damages that have to be assessed are both physical damages, which affect the exposed items, and the disruption of services and functions that may or not result from physical damage (Menoni et al., 2016). Thirdly, as for the spatial scale, it is important to identify the community that has been affected, whether it is a municipality, a region, a nation or across bordering region. The model proposed by Menoni et al. (2016) considers three spatial scales of analysis: the level of the individual item, the municipality level and the meso-scale or macroscale (e.g. province, a region and nation). This differentiation permits during the phase of damage data reporting to select the most appropriate level of analysis regarding the damaging dynamics that may propagate from a local scale (e.g. surveyed physical damage to assets and buildings) to a larger scale (e.g. induced systemic damage producing malfunction to critical infrastructures).

Finally, concerning the temporal scale, the model proposes to take into account the dynamics of damage evolution. Indeed, it is crucial to consider that some damages, especially induced damage, due to ripple effects across systems may become manifest only sometime later, even weeks or months (Menoni et al., 2016).

Table 9 Structure of post-flood damage assessment model by Menoni et al. (source: Menoni et al., 2016).



Exposed sector	Type of damage	Spatial scales of analysis		
		Individual item	Municipality	Meso-/macroscale (province, region, country)
Population	Physical damage	X	X	
	Evacuated people		X	
	Psychological distress	X		
	Unemployment, loss in salary, etc.			X
	Lack of services		X	X
Infrastructures (installations and lines)	Physical damage	X		
	Functional disruption		X	X
	Physical and functional systemic damage		X	X
Public services	Physical damage	X		
	Functional disruption	X	X	X
	Physical and functional systemic damage		X	X
Economic activities	Physical damage	X		
	Functional disruption	X	X (district)	X (district)
	Physical and functional systemic damage	X		
Private properties (residences and cars)	Physical damage	X	X (cars)	
	Functional disruption	X		
	Physical and functional systemic damage	X		
	Loss of value		X	
Environmental and cultural heritage	Physical damage	X	X	X
	Functional disruption	X	X	X
	Physical and functional systemic damage		X	X
Civil protection	Costs of emergency services		X	X

The above policy review shows that there are many purposes and applications for disaster damage data and specifically for post-flood damage data that are intersecting. On the one hand, most purposes comprise supporting evidence-based disaster risk management actions and the implementation of disaster risk reduction strategies, and, in particular, the selection and implementation of flood risk management measures. On the other hand, disaster damage data usages consider in some cases disaster forensic investigation as a specific use but mostly include more general data applications that somehow intersect with forensic analysis. These comprise the understanding of all dimensions of disaster risk and flood risk assessment. Therefore, all the reviewed policies were considered for the definition the required post-flood damage data categories for forensic investigation.

Table 10 shows the post-flood damage data categories for forensic investigation, as defined from the previous policy analysis and literature review. It contains the data categories that need to be collected after a flood event, as well as its spatial scale. Main data categories include Hazard event, Damaged object or sector, and the damage per se. As De Groeve et al. (2013) recommend, data on damages and damaged objects should be collected at an asset level, along with georeferencing this element. The spatial scale for hazard event data is not addressed in the reviewed literature.

Table 10 Post-flood damage data categories for forensic investigation (source: author).

	Post-flood damage data categories			
	Hazard event	**Damaged sector/object**	**Damage**	
			Damage typology	Damage representation
Examples	Flood characteristics (e.g. flood extent, water depth, velocity)	People, critical infrastructure, networks, economic activities, residential buildings, the environment and cultural heritage.	Physical damage, outage, disruption, second order, systemic, etc.	Quantity of damaged objects, cost/monetary value, number of disruptions, etc.
Spatial scale / dimension	N/A	Asset level (georeferencing damaged object)	Asset level	

3.5 DAMAGE DATA COLLECTION IN EUROPEAN PRACTICES

Even if different policies have called for the collection of disaster damage data, there is still no specific European legislation addressing disaster loss databases (De Groeve et al., 2013). The 2014 EU report titled "Current status and best practices for disaster loss data recording in EU Member States" presents the state of the art for recording disaster loss data in 15 European Union member states (De Groeve et al., 2014). The 15 case studies that are detailed in this report describe for each member state i) the methodologies of damage data collection and recording ii) the purposes of damage data collection and iii) the model of existing loss databases when they are present.

This overview shows that the process of damage data collection is actually a two-steps process: 1) damage data collection as such, which permits to assess and measure the damage and 2) damage data recording in an organized way (e.g., storing it in a previously modelled database). In the following, the damage data collection process is explored in terms of the actors who are collecting and storing data, how they perform these activities, and which are the characteristics of damage data that are managed.

Damage data collection in Europe is a process that involves several actors. An actor models a type of role played by individuals or organizations that collect, record, organize and use damage data. Actors involved in the collection of damage data are mainly public structures such as Civil Protection organizations, governmental entities and public administration agencies at different administrative levels. Moreover, they may include private/public organizations such as insurance companies, research institutions and Universities. In addition, among the classes of actors that collect damage data directly on the field, for internal and personal use, we find the affected private actors such as private companies and citizens. For example, results of the IDEA project showed that utility companies collect damage data for their own accountability, for compensation, to manage repairs and for service restitution to affected users. Damage data collection techniques comprise desk research of media reporting or government reports, sectorial field assessments, sampled surveys, insurance or compensation claims, police or emergency intervention reports and remote sensing (satellite or airborne assessments) (De Groeve et al., 2014).

Damage data recording in Europe is also a process that involves different actors, which do not necessarily coincide with the actors who collect (De Groeve et al., 2014). Actors that record damage data include the Civil Protection departments at different levels, public administrations, ministries and agencies at different administrative levels, insurance companies and academic and research institutions. Moreover, meetings with involved actors during the IDEA project revealed that private companies, such as utility (water provision, electricity, etc.), telecom and transportation companies, also record damage data and are supported by their own databases. Recording damage data in organized formats vary across EU countries, as it is possible to find paper-based documents but mostly they are shifting towards IT-based supports. Indeed, these digitalized formats may be file-based (e.g. Excel spreadsheets with tables), a unique database or a set of integrated databases (information systems).

A review of selected cases of damage data collection in Europe is performed that focuses on selected digitalized databases that are currently available for the storage and access to damage data in Germany, Italy and Spain. These platforms are specifically related to flood events losses and damage reporting. This review supports the analysis of the existing practices in damage data collection and recording in Europe and permits to explore in detail the categories of damage data that are collected. The analysed databases are HOWAS21 in Germany, FloodCat and Italia Sicura in Italy and the "Catálogo Nacional de Inundaciones Históricas" (National Historic Floods Catalogue) in Spain. Table 11 synthesises the results of the review in terms of the spatial and temporal scales of the damage data that is recorded in the databases under analysis, the damage data categories included and the purpose of the damage data collection.

HOWAS21 is a flood damage database established by the GFZ Potsdam in 2007 as part of the MEDIS-project (Methods for the Evaluation of Direct and Indirect Flood Losses). The main purpose of HOWAS21 is to record damages for developing damage functions and forensic analysis (De Groeve et al., 2014). With the establishment of HOWAS21, standards for the collection of damage data were developed for the residential, commercial and industrial sectors, public infrastructure, the agricultural sector, transportation and water management (De Groeve et al. 2014). The database contains object-specific data on flood damage and damage determining factors (Elmer et al., 2007).

HOWAS21 relies on voluntary data contributions and holds historic data from the old HOWAS database, as well as more recent damage data from flood events in 2002, 2005 and 2006, collected through Computer-Aided Telephone Interviews (CATI) at the asset-level among affected households and commercial activities after the flood events (Kreibich et al., 2017). Available data in HOWAS21 does not include all the affected households and commercial activities in the flooded area, but it represents a subset. This means that coverage is incomplete: the aggregation of data from the asset level to a higher level does not provide the total loss in that area (De Groeve et al., 2014).

Table 11 Overview of damage data characterization in damage data management existing information systems (source: author).

Country	**Information System**	**Spatial scale of damage data**	**Temporal scale of damage data**	**Damage Data categories**	**DD collection /analysis purposes**
Italy	Italia Sicura	Structural measures at communal and object levels. Exposed sectors at the National level. State of emergency at regional and national levels.	Event-based (state of emergency)	- Flood and landslide hazard (qualitative levels). - Exposed population, schools, cultural heritage. - Structural measure (location, number of construction sites, total investment costs and construction status). - State of emergency (status, location, date, authority, associated official documents, the total monetary amount requested and allocated, the monetary amount of damages declared by the authority in charge).	-Enhance citizens' awareness of flood risk.
Italy	FloodCat	Phenomenon spatial scale: areal (polygon). Damage spatial scale: asset level (point and line), areal (polygon).	Event-based	- Event (competent authority, category, date and time, duration, flooded area, return period). - Phenomenon (description, flood typology and mechanism, location). - Damage (description, date, flood mechanism, damage category/subcategory, quantity, economic value, damage class, location).	-Risk assessment (compliance with Floods Directive).
Spain	Catálogo Nacional de Inundaciones Históricas	Municipal and regional scale	Event-based	- Event (date, time, climate data, hydrological data). - Affected area. - Damage to population (Number of deaths, injured, evacuees). - Damage to residential buildings (number of damaged households, damage in monetary terms). - Damage to hydraulic and transportation infrastructure (affected section, damage level, damage in monetary terms). - Damage to agriculture and livestock (affected surface, damage in monetary terms, number of livestock). - Damage to industry (number of industries, damage in monetary terms). - Damage to Basic services (in monetary terms).	- Systematizing and homogenizing the collection of data on historic floods at the national level. - Serve both technicians and the general public, to better understand the history of flood damage in Spain.

Country	**Information System**	**Spatial scale of damage data**	**Temporal scale of damage data**	**Damage Data categories**	**DD collection /analysis purposes**
Germany	HOWAS21	Loss recording at the object level. Aggregation of data from the asset level to a higher level is not possible.	Event-based (flood)	- Event (e.g. date of flood occurrence, type of flood, flood characteristics). - Damaged object (e.g. building type and materials). - Damage reduction (e.g. warning time, prevention/emergency measures). -Damage residential/commercial building and content (replacement costs and physical damage). -Flood effects on health/wellbeing	Risk modelling (developing damage functions) and forensic analysis.

The questionnaire for the affected households addresses the following topics: Flood characteristics, flood warning, emergency measures, evacuation, damage to building and contents, characteristics of building and contents, recovery, precautionary measures, flood experience, socio-economic variables (Thieken et al., 2005). Questions on the flood effects on health and wellbeing, as well as flood severity perception, were added for the surveys performed for the 2013 flood event (Thieken et al., 2016a).

Accessibility to data stored in HOWAS21 depends on the type of user. The administration (GFZ Potsdam) has unlimited access, users that provide damage data have unlimited reading access, users without own data have limited reading access and need to file requests for data use, while the user group "world" can only use predefined analysis (Elmer et al., 2007). In spite of the existence of the HOWAS21 database, damage data is not recorded for all the significant flood events. For example, data on damages of the 2013 floods in Germany are not stored yet in HOWAS21 due to restrictions in data ownership.

FloodCat and *Italia Sicura* are two recent national projects developed in Italy for flood damages and flood risk management data. The *Italia Sicura* national project promoted by the Italian Presidency of the Council of Ministers proposed an information system that stores data on structural measures for floods and landslide mitigation, as well as data on emergency declarations and associated damages. Data on emergency declarations and damages are recorded in the aftermath of any declaration of a state of emergency, at provincial and regional scales. Instead, data related to structural measures are at both communal and object level. *Italia Sicura* has an open portal (mappa.italiasicura.gov.it) where data are constantly updated, georeferenced and presented on a map.

On the other hand, *FloodCat*, established for complying with the Floods Directive requirements, consists on a closed web application accessible only for Competent Authorities that allows inserting, visualizing and analysing data related to past flood events. Data managed by *FloodCat* are stored in a central database, specifically designed in compliance with the European guidelines for the implementation of the Floods Directive. Data are recorded in the aftermath of a flooding damaging event, at the object and higher areal levels.

The third example is the *Catálogo Nacional de Inundaciones Históricas* (National Historic Floods Catalogue) in Spain, a database where data describing the historical flood events in Spain and related loss and damage data are stored. The national Civil Protection has been working on the development and updating of this database since

1995, including territorial modifications after the Floods Directive. The data present in the database are collected and inserted when the event finishes, and final data are concluded. These data result from an aggregation performed at several geographical scales (municipal, provincial and basin levels).

4 RESEARCH METHODOLOGY

This chapter starts with the statement of the research rationale and questions. It presents then the process designed for conducting this research. Next, a crucial part of this chapter is the development of the New Disaster Forensic Investigation method, which is then used for the case study analyses. This chapter ends with the selection of the case studies and the description of the case studies data collection and analysis.

4.1 RESEARCH RATIONALE

Spatial planning, as all purposeful action, rests on the use of information (Mcloughlin, 1969). The compound of this information has been given different names, one of which is knowledge base ("quadro conoscitivo" in Italian). Friedmann (1993) defines planning as the professional practice that pursues the linking of knowledge to action. Knowledge is then an essential factor in steering territorial transformations and managing development (Carta, 1996). This "knowledge base" must contain all the information necessary for analysing the context in which the plan operates and on which to base action. However, the definition of the knowledge that is "necessary" for planning is not banal nor linear, because it involves characterising and analysing cities and territories, which are complex in nature. That is, "cities are complex three-dimensional spaces in which social, political and economic organisations interact in different ways and at multiple levels with buildings, infrastructures, production and service facilities, open areas" (Atun & Menoni, 2017:54). In fact, Carta (1996) widely discusses this issue stressing the impossibility of reaching the complete knowledge of a complex system, such as the city and the territory. According to Carta (1996), "knowing is to select; investigating the territory is equivalent to reducing its elements, implementing a 'discretization' of the variables, capable of not losing the intrinsic and configuring relationships of the system" (p. 59, translated by the author).

The question is then what to know or what "territorial categories" to select, vital to represent the territory and to plan (Carta, 1996). A possible answer was given by Besio (1994), as quoted in (Carta, 1996): the geological and biotic structure, the human activities, the places for living, the flows of goods, people and information, the settlements and land transformations. As a matter of fact, generally, plans include information such as the activities, vacant or unused land, demography (current and projected), the economic system, the mobility system, services, green and open areas, etc. It should, however, comprise also knowledge on Disaster Risk Reduction (DRR), as requested by both DRR and Urban policies.

In this research, DRR is defined not just as the concept and practice of reducing disaster risk but mainly of preventing it. Risk prevention means avoiding the generation of new disaster risk, whereas risk reduction focuses on the mitigation of existing risk. As shown in Chapter 2, the knowledge base on DRR in spatial planning at different levels is generally either missing or, if present, it constitutes a separate unconnected part of the plan. This DRR knowledge is not integrated into the actions that are taken within the plans and is insufficient to support them.

The issue is not only to define the categories of information and the knowledge to consider for plan making but to ensure that this knowledge is "actionable", i.e. that it can be translated into action. Disaster Forensic Investigation, one of the recently recognised uses of disaster damage data, is a comprehensive analysis performed after a disaster to acquire lessons learned. Disaster Forensic Investigation can provide "actionable" DRR knowledge to enrich the current knowledge base used in Spatial Planning. Thanks to this, it would be possible to take advantage of the potential that spatial planning holds for risk prevention and reduction.

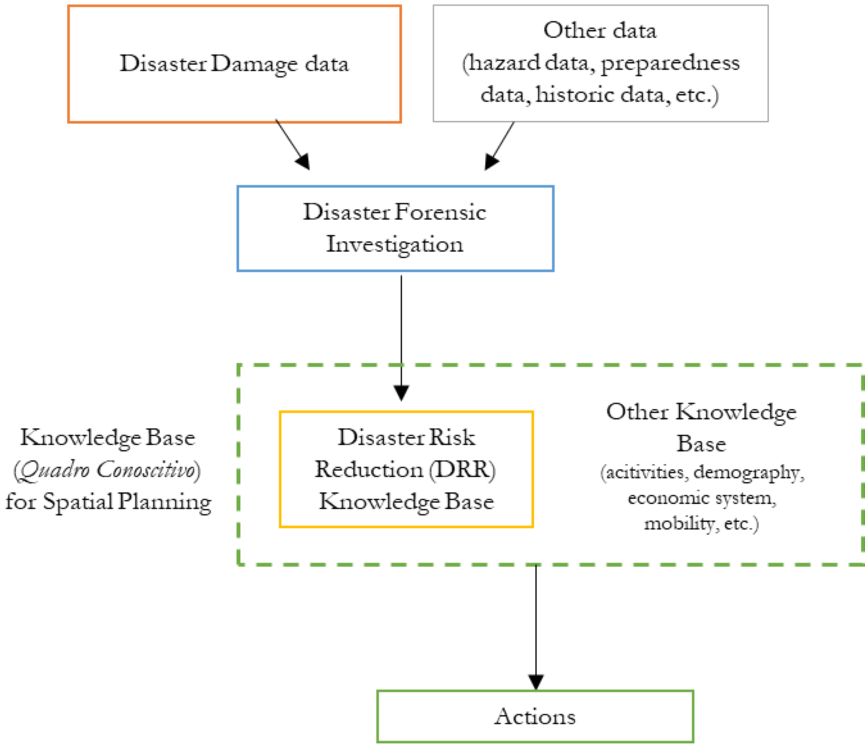


Figure 8 Rationale behind the research project (source: author).

Figure 8 illustrates the rationale behind this research. It shows that the application of Disaster Forensic Investigation requires disaster damage data in addition to other data (e.g. data on the hazard, on preparedness and response, historical data on population and land use, existing protection infrastructure, etc.), as shown in Chapter 3. The data categories required for disaster forensic investigation are also analysed in this research, as well as the assessment of the fitness of the post-flood damage data collection processes for disaster forensic investigation, in

Chapter 7. The results from the forensic investigation can be added to the knowledge base currently used in Spatial Planning, in the form of DRR knowledge, to support action.

4.2 RESEARCH QUESTIONS

Initially, the idea was to study existing disaster forensic investigation methods in order to explore its use for enhancing the current knowledge base used in spatial planning. The interest was in finding a method that provided a comprehensive analysis of a disaster to (i) understand the causes of the disaster and its damages, and (ii) to identify the role of spatial planning in shaping disaster risk (i.e. whether spatial planning is a relevant disaster risk driver or whether spatial planning contributed to disaster risk prevention or reduction). However, the literature review on existing methods (chapter 3) revealed that approaches designed specifically for analysing disasters from a comprehensive perspective are at the beginning of their development. The process that needs to be followed to perform an analysis of this kind is seldom clear. Whilst existing applications of more recently developed approaches are still very few. Besides, from just the theoretical analysis of existing methods, it is not possible to grasp fully how disaster forensic investigation can improve the knowledge base in spatial planning at different levels. Likewise, existing forensic approaches limit themselves to the analysis of how exposure and vulnerability evolved in time, whilst the role of spatial planning is marginally considered. In consequence, the research project addresses two main questions:

(i) How to perform a Disaster Forensic Investigation that considers the role of Spatial planning in shaping disaster risk?
(ii) Can Disaster Forensic Investigation improve the current DRR knowledge base used in Spatial Planning? At what levels?

4.3 RESEARCH DESIGN

Figure 9 shows the process designed for conducting this research study, where each box represents a step. The first step is the analysis of the principal DRR and urban policies to understand the way in which they recommend approaching spatial planning to prevent and reduce disaster risk. The second step is the study of the state of the art on the DRR knowledge base on floods in spatial planning in order to understand what happens in practice. The analysis aims at identifying the information related to flood hazard, flood risk or flood management that is currently present in the knowledge base used in spatial planning at different levels. This analysis starts with the European Flood Risk Management Plans. It continues with the state of the art in Italian Regional Planning. Last, the Local Planning level is studied in selected EU countries (Italy, France and Germany).

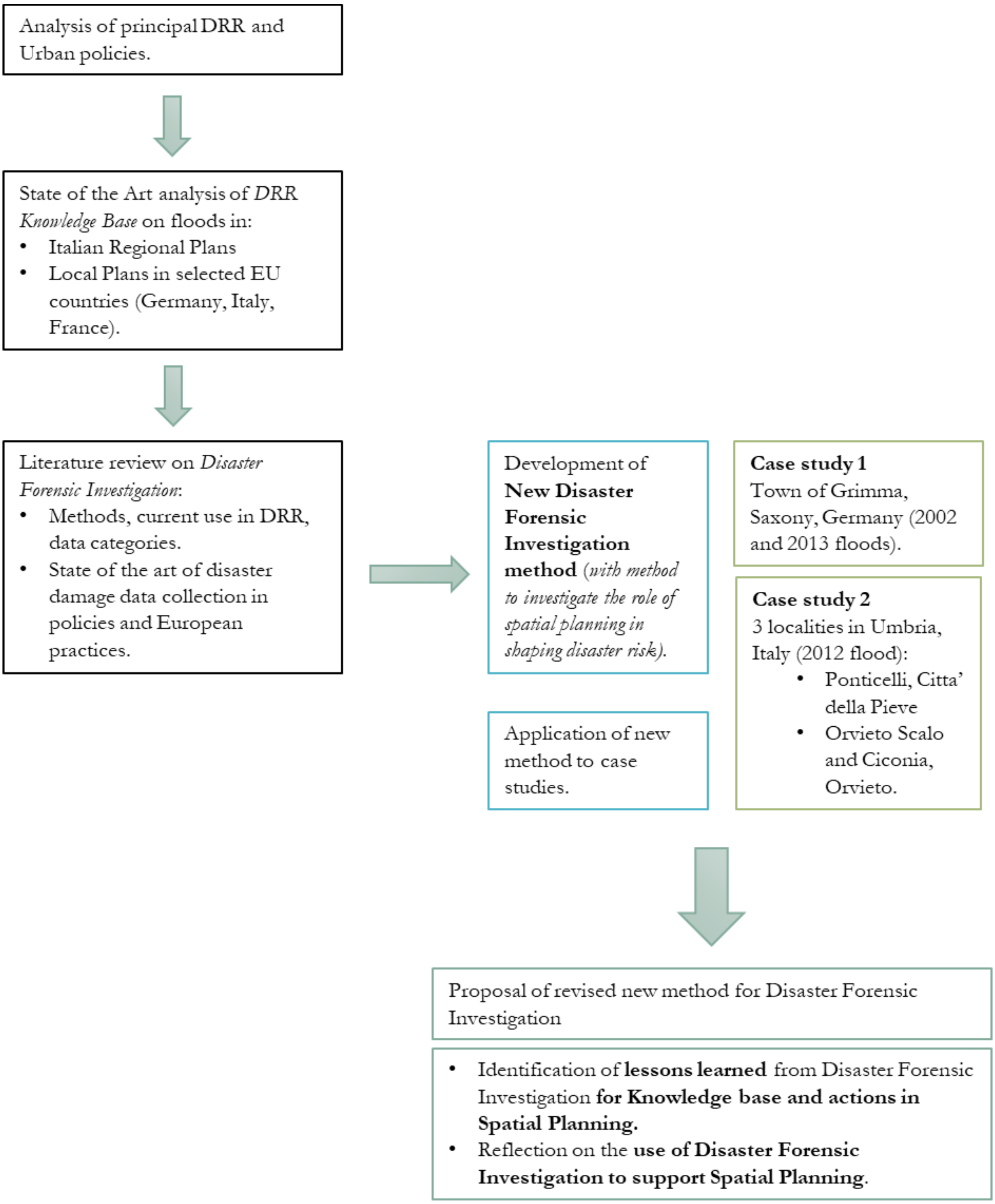


Figure 9 Research design (source: author).

The third step is the literature review on existing methods for Disaster Forensic Investigation, their purpose and use in DRR and the data that they require. This literature review permits to develop a list of existing approaches that acts as a starting point for the development of a new Disaster Forensic Investigation method. Forensic investigation is one of the many usages of disaster damage data collection. Disaster damage data are collected by different actors for multiple purposes, which challenges the usability of the disaster damage data for other purposes than the one for which it was originally collected. Therefore, this review is completed with the state of the art on disaster damage data collection in international policies and in practice in the European context.

The fourth step is the development of a new Disaster Forensic Investigation method to extract lessons learned after a disaster. This method aims at (i) understanding the causes of the disaster and its damages, and (ii) identifying the role of spatial planning in shaping disaster risk. The development of the new Disaster Forensic Investigation method is explained in detail in the next paragraph. The next step is the application of the new Disaster Forensic Investigation method to two main case studies. The case studies and their selection are explained later in this chapter.

The development of the new Disaster Forensic Investigation method constitutes an exploratory part of the research, which proved to be an iterative process. This method (as proposed next in this chapter) was improved during its application to the case studies, which lead in the end to the proposal of a revised new method for forensic investigation for future studies. One of the lasts steps of the research process is then the proposal of this revised new method for Disaster Forensic Investigation, which represents the optimal method to follow in future analyses. Moreover, given that the characteristics of the damage data can condition the analysis and the applicability of this forensic investigation method, the post-flood damage data collection processes in the Grimma and Umbria case studies are assessed according to their fitness for forensic investigation.

The last step involves the analysis of the lessons learned extracted through the Disaster Forensic Investigation in the case studies. The aim of this examination is to determine whether and how these lessons can enhance the DRR knowledge base used in Spatial Planning. This analysis, in conjunction with the state of the art of the DRR knowledge base in regional and local spatial planning, enables also to reflect on the use of Disaster Forensic Investigation to support Spatial Planning at different levels.

4.4 DEVELOPMENT OF THE NEW DISASTER FORENSIC INVESTIGATION METHOD

In the context of this research, I developed a new Disaster Forensic Investigation method. The purpose of the method is to perform a comprehensive analysis of a disaster to extract lessons learned regarding (i) the causes of the disaster and its damages, and (ii) the role of spatial planning in shaping disaster risk. This last point can include both negative and positive aspects, i.e. whether spatial planning is a relevant disaster risk driver or whether spatial planning contributed to disaster risk prevention and/or reduction.

An important characteristic of the disaster forensic investigation I want to develop is to understand the causes and contributing factors of a disaster and its impacts (specifically of floods) from a comprehensive perspective. Cities (and territories) are complex and interdependent systems, where "the very features that make cities feasible and desirable—their architectural structures, population concentrations, places of assembly, and interconnected infrastructure systems—also put them at high risk to floods" (Godschalk, 2003: 136). Cities possess the same characteristics of complex systems, including the nonlinear interrelationships between systems and components, the path dependency of decisions and the difficulty of predicting their response to external forcing (as in the case of floods) (Atun & Menoni, 2017). This complexity is reflected also in the fact that there is not one single factor that can be identified as the cause for the damages of a flood, but generally, it is the combination of several factors that are accountable for the flood impacts. The nonlinear interactions between components make it impossible to predetermine their future interactions (Atun & Menoni, 2017), whilst the nonstationarity in complex systems' responses to external forcing (Park et al., 2013) determines that the impacts of a flood could be different if it happened in different moments in time.

Therefore, it is vital to adopt a holistic perspective that considers all the aspects that are relevant for explaining disaster impacts and that respects the complexity that characterises urban disasters. The development of the new Disaster Forensic Investigation method starts from the state of the art on existing methods for forensic investigation (chapter 3). The review shows a multiplicity of approaches, often motivated by the objectives they pursue. Most of these methods focus on a specific aspect of the disaster due to their objective or the discipline in which they were developed. For instance, forensic flood hydrology (a branch of forensic engineering) studies the impacts that diverse factors like floodplain development have in augmenting flood hazard (i.e. the water depth) and, in consequence, flood damages. This approach exclusively analyses the hazard factor in damage causality, neglecting any other factors like exposure and vulnerability. On the other hand, there are several approaches concerned with the analysis of emergency management during disaster response. They aim at identifying failures and successes in crisis management to learn for future events.

With this in mind, the starting point for the development of the new method are those existing approaches that investigate multiple aspects of disasters and pursue a comprehensive analysis. These methods were developed in recent years specifically for the study of disasters (for DRR policy-making and practice) and, hence, are the most comprehensive ones. They consider all the phases of the risk management cycle (i.e. prevention, preparedness, response and recovery), as well as the different risk factors (hazard, exposure and vulnerability). These methods were catalogued as "Disaster Forensics" in Chapter 3 and are listed in Table 12.

Table 12 List of existing disaster forensic investigation methods classified as "Disaster Forensics" (source: author).

Typology of Disaster Forensic methods	**Existing methods**
"Disaster Forensics" (comprehensive methods)	Forensic Disaster Analysis in near real time (CEDIM, 2012)
	Detecting Disaster Root Causes (DKKV, 2012)
	PERC Post Event Review Capability (Zurich Insurance, 2015)
	FORIN Forensic Investigations of Disasters (IRDR, 2016)

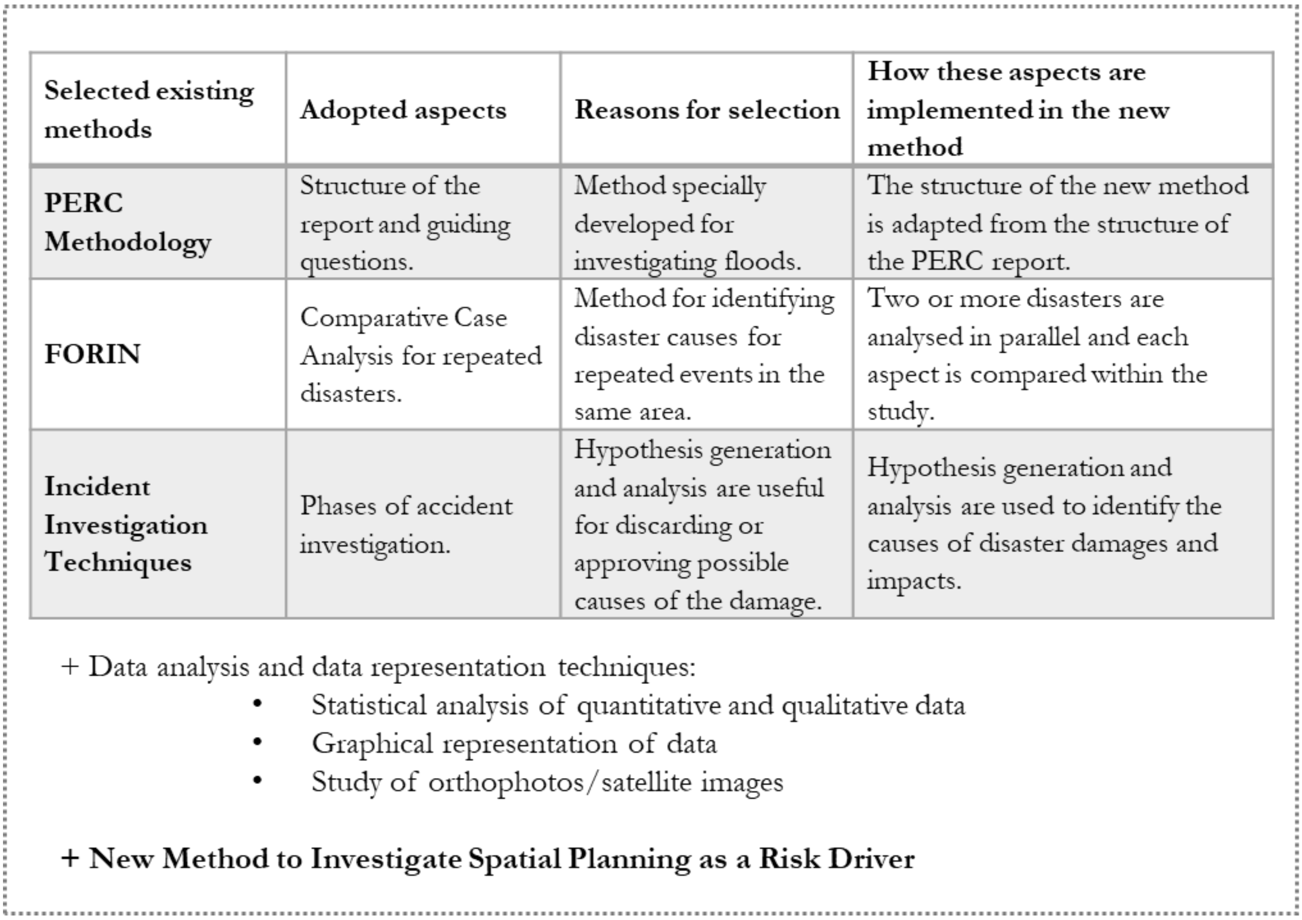
CEDIM's Forensic Disaster Analysis was designed to provide results useful for the emergency management phase and requiring "near real-time" data (i.e. data produced during the crisis). Therefore, this method is out of the scope of this work performed ex-post and based on post-flood damage data. On the other hand, the method developed by the DKKV is based on already available analyses of the disaster made by experts of different kinds. It does not provide an alternative approach for the cases where these expert analyses are missing, and it does not make use of post-flood damage data. Consequently, "Detecting Disaster Root Causes" by the DKKV is also unsuitable for this research.

Figure 10 shows the process followed in the development of the new method for Disaster Forensic Investigation. The table in the figure lists the existing methods that were selected for the development of the new method (i.e. PERC, FORIN and incident investigation techniques). These methods were chosen for different reasons, listed in the table. The first one is PERC, selected because it was developed for analysing flood events and, thus, its structure is considered very convenient for investigating this kind of disasters. The second method is

FORIN, picked due to the approach that it proposes for investigating repeated events, useful to analyse two or more floods in the same area. The last selected method actually comprises a group of techniques for incident investigation, as presented in Chapter 3. These techniques follow the phases of accident investigation, which are useful for the study of damage causality for the new method. These phases comprise the generation of hypotheses that are then analysed, discarded or approved. The last column in the table in Figure 10 explains how each of the aspects that were adopted from the existing methods is implemented in the new forensic investigation method. In the case of PERC, the structure of the new method is an adaptation of the structure of the PERC report. The new method includes a parallel analysis of two or more floods to compare each aspect under investigation, adopted from FORIN's comparative case analysis. This comparison allows discerning the relevant aspects that played a part in the generation of the disaster and its impacts. The phases of accident investigation are integrated into the new disaster forensic method to generate hypotheses and discard or approve possible causes of damages. Figure 10 shows, under the table of selected methods, other elements that are integrated to complete the new disaster forensic investigation method. These are different techniques for data analysis and representation, and a new method that I developed to investigate the role of spatial planning in shaping disaster risk. This last element is crucial for the new method and is a component that is missing in all existing approaches. This method for investigating spatial planning will be explained thoroughly later. Each of the selected methods is analysed in more detail next, indicating their shortcomings and the aspects that were adopted and how.

The methodology that PERC proposes is mostly structured around informal interviews with key people involved in the disaster and it uses the desk review mostly for an initial understanding of the event. What is interesting is the structure of the report that PERC suggests for organising the collected information. This report is divided into four main sections called "the physical context", "the socio-economic disaster landscape", the "what happened" section and the "key insights". Each section addresses different aspects of the disaster and the disaster management cycle. For example, the "physical context section" includes information on the hazard (e.g. flood frequency and severity). The "socio-economic disaster landscape" describes risk and vulnerability, as well as the actions taken for risk reduction and preparedness. The "what happened" section contains the description of the disaster impacts, the response, the recovery process and on the learning of actors involved in the disaster.

Each section in the PERC report includes questions that should guide the analyst in selecting what information to include. However, these guiding questions cannot be easily and immediately answered. PERC lacks the proposal of a method to analyse all the collected information in a way that they can be used to answer the guiding questions to "fill" the sections of the report. This is also true when the PERC report addresses the damages and impacts of the flood. It limits itself to the description of these damages, which generally is insufficient for identifying the causes or factors that had an influence in their generation. It does not provide nor suggest a method for analysing disaster damages and impacts. Hence, the PERC methodology fails to identify the causes of the flood damages and impacts that are not immediate, which require analysis. Nevertheless, the structure of the PERC report with its guiding questions is retained useful for the development of the new forensic investigation method. This structure and questions indicate the aspects that require investigation to identify the causes of disaster damages. Consequently, the structure of the new method is adapted from the structure of the PERC report, maintaining most of its sections. Instead of guiding questions, the new method contains subsections or bullet points that specify the factors and aspects that require investigation. The new method finishes with the extraction of the lessons learned, which in the PERC method are named “key insights”, leaving out the section on recommendations in PERC that are meant for DRR policy and practice.



Selected existing methods	**Adopted aspects**	**Reasons for selection**	**How these aspects are implemented in the new method**
PERC Methodology	Structure of the report and guiding questions.	Method specially developed for investigating floods.	The structure of the new method is adapted from the structure of the PERC report.
FORIN	Comparative Case Analysis for repeated disasters.	Method for identifying disaster causes for repeated events in the same area.	Two or more disasters are analysed in parallel and each aspect is compared within the study.
Incident Investigation Techniques	Phases of accident investigation.	Hypothesis generation and analysis are useful for discarding or approving possible causes of the damage.	Hypothesis generation and analysis are used to identify the causes of disaster damages and impacts.

\+ Data analysis and data representation techniques:

- Statistical analysis of quantitative and qualitative data
- Graphical representation of data
- Study of orthophotos/satellite images

+ New Method to Investigate Spatial Planning as a Risk Driver

Figure 10 Development process of the New Disaster Forensic Investigation method (source: author).

The FORIN conceptual framework is organised around a causal chain that starts from a descriptive analysis, moves to the identification of the risk drivers and arrives at the root causes, the last piece of the causal chain. Root causes are intended as “larger social and cultural processes, practices and priorities” (Oliver-Smith et al., 2016: 31). Even if FORIN’s conceptual framework is well structured, it does not suggest methodologies to identify the risk drivers and rather explicitly leaves this aspect to the analyst or researcher. Yet, FORIN does suggest some forensic research approaches that aim at identifying the root causes of disasters. The aim of the new method I am developing is not the identification of root causes, but rather what in FORIN would be “more immediate” damage causes and disaster risk drivers. However, the *comparative case analysis* proposed by FORIN for identifying root causes appears to be also useful for identifying the causes of disaster damages and impacts. It consists of a limited quantity of detailed analyses of several disaster events that are comparative in-situ (same place, repeated events) (Oliver-Smith et al., 2016). For our method, the comparative case analysis “in-situ” is useful for cases where at least two floods occurred in the same area. FORIN does not explain how to do this evaluation. However, the new method under development takes from FORIN the idea of analysing in detail two or more events and to compare them to identify disaster and damage causes.

Even if the Incident Investigation Techniques (Chapter 3) are not methods for specifically investigating disasters as intended in this research, they can be useful to study some of the aspects of a disaster. In detail, the new method under development follows the phases of accident investigation, as proposed in (ESReDA, 2009), to perform an in-depth analysis to identify the factors that influenced the damages of a flood. This means that different hypotheses are generated on what caused specific damage or impact and then they are analysed to approve or discard them. In this way, the causes of disaster damages and impacts can be identified.

A recurrent aspect of existing methods is the lack of techniques to analyse and "put together" the collected data. PERC is good at defining the aspects that require analysis but fails at explaining how to combine all these aspects to arrive at the "key insights", as they call them. The PERC manual (Venkateswaran et al., 2015) invites to "put it all together", by organising and analysing the collected information to identify key insights. Nevertheless, it does not provide a way to analyse this data. Most of the times, the key insights or lessons learned are not immediately recognisable or extractable from just organising the information. They require an analysis. This is the only way to link all the different aspects of the disaster, which are studied in the different sections of the report. Similarly, methods of analysis in FORIN are proposed only for root cause analysis, while analysis at the level of risk drivers and risk factors (i.e. hazard, exposure and vulnerability) are not considered. FORIN leaves the methodological aspect to the discretion of the analyst performing the forensic investigation.

For the new method, in order to "put together" the collected data, I propose to use different techniques for data analysis and data representation. These are listed in Figure 10, under the table on existing methods. They include statistical analysis of quantitative and qualitative data, graphical representations of data (charts of different kinds) and the study of orthophotos and satellite images. On the one hand, both the data analysis and the graphical representations support the analyst in understanding and interpreting the different aspects of the disaster. On the other hand, they assist the analyst in the process of combining the data regarding the different aspects of the disaster in order to extract lessons learned.

Data analysis and graphs are particularly useful for analysing disaster damages and impacts. For example, the use of line graphs for visualising time series data (e.g. on the population) can reveal changes in trends and impacts that can be motivated by the disaster. Bar charts are very useful for comparing rapidly two flood events (e.g. by representing the water depth, the total economic damages, the warning time, etc.). Cake charts allow visual and immediate understanding of disaster impacts, for example on the weight that each damaged sector (e.g. residential, industrial, infrastructure, etc.) had in the total damage or on the share of each type of damage within one sector (e.g. damage to the building, machinery or goods for the industrial sector).

Likewise, statistics like the mean and median of a sample provide indicative values that help also in interpreting the collected data. The availability of data and its quality, especially of damage data, often limits the kind of statistical analysis that can be done. Therefore, one must be careful in the application of statistics because samples are generally small and not necessarily representative of the whole population. It is important to mention that when statistical analysis is not possible (due to the size or the heterogeneity of the sample) available data are used anyhow, attempting to find evidence from different sources to support them.

Another shortcoming of existing forensic investigation methods, which the new method seeks to overcome, is the lack of a way to investigate whether poor spatial planning is a relevant disaster risk driver. Likewise, existing methods fail at indicating when spatial planning had a positive role in preventing or reducing disaster risk. Methods like PERC and FORIN do not consider adequately spatial planning as a relevant element in the generation of exposure and vulnerability of cities and territories. However, due to the path dependency that characterises complex systems, this is a critical aspect. This is particularly true regarding locational decisions and the development of unoccupied land (Atun & Menoni, 2017). Once this decision is taken, the area becomes buildable, taking a path that cannot be easily changed and that is in most cases irreversible. As Carta (1996) explains, it is not always possible to intervene to bring back a system: the "arrow" of time does not allow it, and turning back is always going forward, reproducing through energy consumption (economic, social, urban, etc.) a part of the past and consuming a part of the future. Indeed, buildable lands in flood-prone areas eventually become built and usually stay built forever. Even worse, sometimes a whole settlement is established in time around that area due to that first decision to declare it buildable land or to encourage development. These planning decisions in flood-prone areas set a path that projects into the future, determining flood risk and, eventually, flood damages and impacts.

Solutions for "turning back" the system like relocation and re-naturalisation are very difficult to implement (sometimes impossible) and require a lot of "work" (as in energy and resources). It is impossible then to go back to the initial situation, to the state of the system when planning decisions were taken in the first place. This is why the role of spatial planning is crucial in shaping disaster risk, and the reason why it needs to be analysed in the new disaster forensic method.

Both PERC and FORIN ask to study the evolution of exposure and vulnerability through time and space, but hardly consider the role spatial planning had on these changes. Only the existence of norms that limit the development of more exposure and vulnerability is mentioned as an important factor for investigation. In any case, they do not provide a method for either studying the evolution of exposure and vulnerability nor to investigate the role that spatial planning had. Figure 10 shows that the development of a new method to investigate the role of spatial planning in shaping disaster risk is the last piece that completes the new method for Disaster Forensic Investigation.

Figure 11 presents the structure of the new method for Disaster Forensic Investigation. It is organised in sections, as proposed in the PERC report. Each section describes and analyses different aspects of the disaster. The white boxes indicate the methods and techniques defined for data analysis within each section. Most of the names of the sections are maintained with respect to the PERC report, while the contents indicated with bullet points are sometimes changed. This is particularly true for Section II.A, where the role of Spatial planning in shaping disaster risk is introduced, as well as the method for investigating it.

Section I, "Physical Context", contains the analysis of the hazard event and the description of past floods. The hazard event refers to the characteristics of the flood under study in terms of hazard parameters, such as flood return period, flood extension, precipitation, etc. The past floods description is focused on important floods that happened in the area under study. Section II, "Socio-Economic Disaster Landscape", is divided into two parts. Section II.A analyses the role of Spatial planning in shaping disaster risk. In contrast, Section II.B follows the original PERC report and analyses changes in flood exposure, as well as the groups of people, services and functions that might be vulnerable during floods. The analysis of changes in exposure and vulnerability of the built environment is done with orthophotos or satellite images studied chronologically. Likewise, it includes the analysis of whether there was any physical protection infrastructure or any other type of flood risk mitigation measure in place before the flood happened.

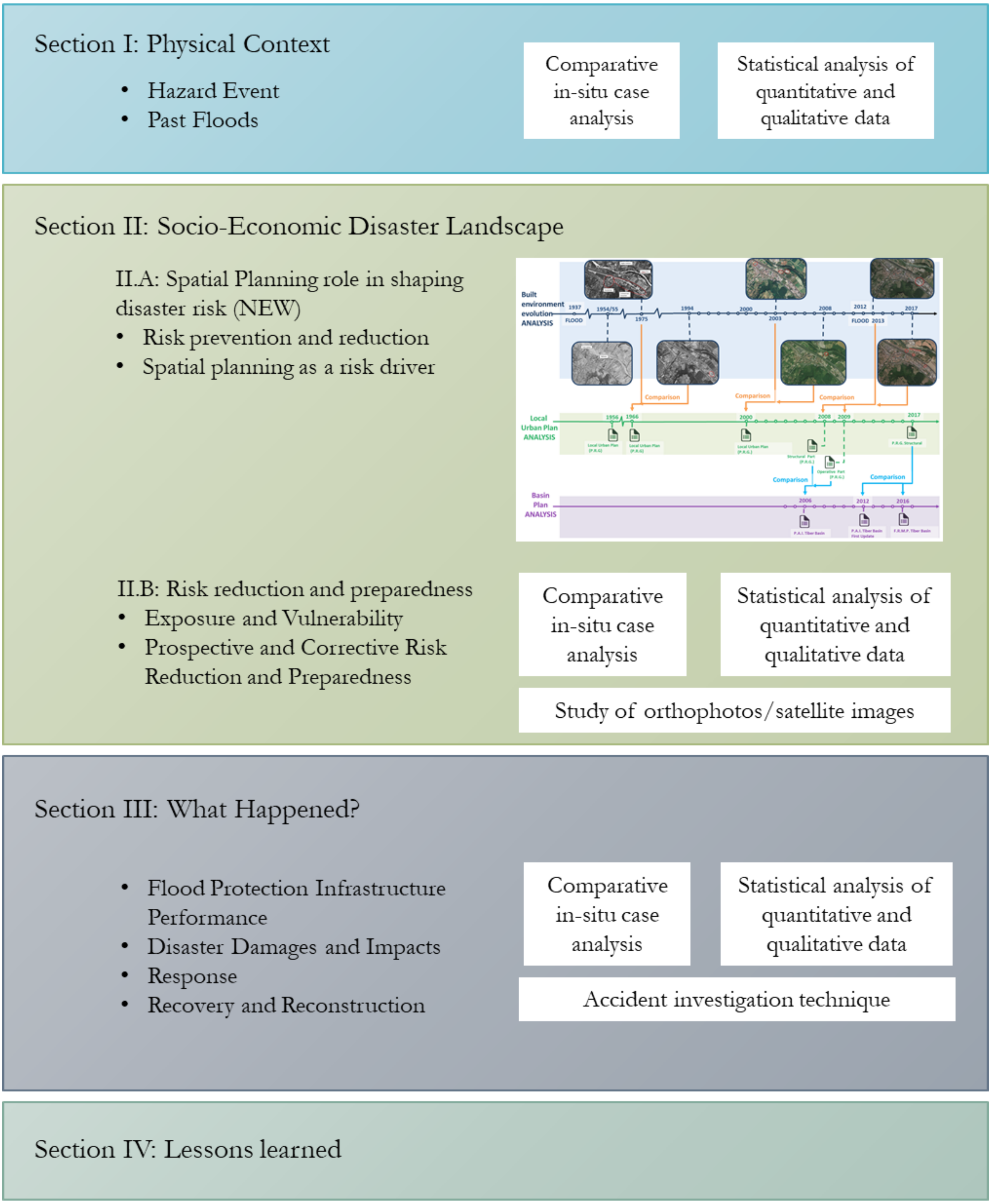


Figure 11 Structure of the new Disaster Forensic Investigation method (source: author).

Section III, “What Happened?”, is the most substantial one. It comprises the analysis of the performance of existing flood protection infrastructure, the analysis of the disaster damages and impacts, the response and the recovery and reconstruction processes. It is within the analysis of the disaster damages that the accident investigation techniques are used. Different hypotheses are generated and tested through the statistical analysis of quantitative and qualitative data. The analysis of the response process focuses on the characteristics and the actions taken during the emergency period (e.g. the warning, evacuation, rescue, etc.). The analysis of the recovery and reconstruction period includes actions taken post-disaster.

The last section, Section IV, is where the lessons learned are extracted. The results of the analyses in the previous sections support the elaboration of these lessons learned.

4.4.1 Development of a method to Investigate Spatial Planning role in shaping Disaster Risk

In this section, I present the new method developed in this thesis to investigate the role of spatial planning in shaping disaster risk. This method completes the new Disaster Forensic Investigation method, as was shown in Figure 10. The UNISDR repeatedly recognised poor spatial planning as a main disaster risk driver, intended as a process or condition that influences the level of disaster risk by increasing levels of exposure and vulnerability (UNISDR, 2017a). However, on the opposite side, spatial planning can have a positive role in preventing and sometimes reducing disaster risk. Thus, the rationale behind the new method to investigate spatial planning is understanding if historic and current spatial plans have shaped the built environment in flood-prone areas and, thus, the resulting flood risk. The aim is to learn from both the positive and negative aspects of the role of spatial planning in shaping disaster risk.

The method consists first in understanding the evolution of the built environment, understanding changes in Local Urban Plans and changes in Basin Plans through time. Then, this first step allows moving to the investigation of the interactions between these three lines of analysis to understand if and how one affected the other. The structure of the method is shown in Figure 12. The timelines represent three different kinds of analysis, all of which must be performed first:

- ✓ The Analysis of the Evolution of the Built Environment
- ✓ The Local Urban Plan Analysis
- ✓ The Basin Plan Analysis

The *Analysis of the Evolution of the Built Environment* focuses on identifying changes in the built environment and visible urban transformations through time up to date. The *Local Urban Plan Analysis* studies local plans and related variations and documents in time. The *Basin Plan Analysis* examines the evolution of Basin Plans. Each analysis can be done independently, but, given that the final goal is to understand if and how local urban plans and basin plans have influenced the evolution of the built environment, some aspects need to be considered before starting the analyses.

It is necessary to check first the date of approval of all historic and in force local urban plans and basin plans. This is important because the aim is to understand if and how each of these plans influenced the evolution of the built environment. Therefore, it is necessary to analyse changes in the built environment before and after each plan was enforced. However, it is important to note that plans shape the environment slowly, so changes after the enforcement of plans are not immediately seen and need to be assessed several years after.

The orange lines in Figure 12 indicate the comparison between the *Analysis of the Evolution of the Built Environment* and the *Local Urban Plan Analysis* to investigate whether local urban plans have shaped the built environment. The turquoise lines in Figure 12 indicate the comparison between the *Local Urban Plan Analysis* and the *Basin Plan Analysis*. These comparisons are explained in detail later because they are based on the results of the three analyses.

The Analysis of the Evolution of the Built Environment is based on orthophotos and satellite images. As explained, the date of these images needs to be defined according to the dates of enforcement of local urban and basin plans. These images are then studied to identify changes in the built environment, before and after the approval of each plan. Therefore, images of the built environment are collected for the years before each plan is enforced and for several years after. The timing of the images after the enforcement of plans is generally conditioned by the availability of either orthophotographs or satellite images. Once these images are collected, they can be analysed with different techniques for satellite imagery analysis. These analyses can provide different kinds of information, both quantitative and qualitative (see for example the Atlas of Urban Expansion by the NYU Urban Expansion Program, UN-Habitat and the Lincoln Institute of Land Policy). Results of the analysis of satellite imagery may include land use maps, building density by area, roads distribution and width, etc. In this research, the orthophotos and satellite images are organised chronologically and studied through a visual comparison to detect qualitative changes in the built environment. As mentioned, other more sophisticated or quantitative analyses are also possible and are convenient for the study of large urban areas.

Figure 12 shows an example of the organisation of these images graphically in the timeline. The first image acts as a baseline from which to start the comparisons. Results are presented also in the form of a table (Table 13), describing the changes in flood exposure, indicating the land-uses identified in each image and whether there are changes in flood exposure. Changes in flood exposure are assessed by considering the changes in the built environment inside the flood-prone area. This flood-prone area corresponds to the flood extension defined by the flood hazard map in the latest basin plan, i.e. the basin plan in force at the date of the analysis. The most recent flood hazard map is used because it is considered to be the most updated information on flood-prone areas. A plus sign (+) in the table indicates that flood exposure increased with respect to the previous image, an equal sign (=) means that flood exposure remained the same, a negative sign (-) means flood exposure decreased.

Table 13 Presentation of results of the Built Environment Analysis (source: author).

Year	**Description of Changes in Exposure**	**Changes in Exposure**	**Land uses**
1956	Baseline	N/A	…
1975	…	+ / - / =	…
…			

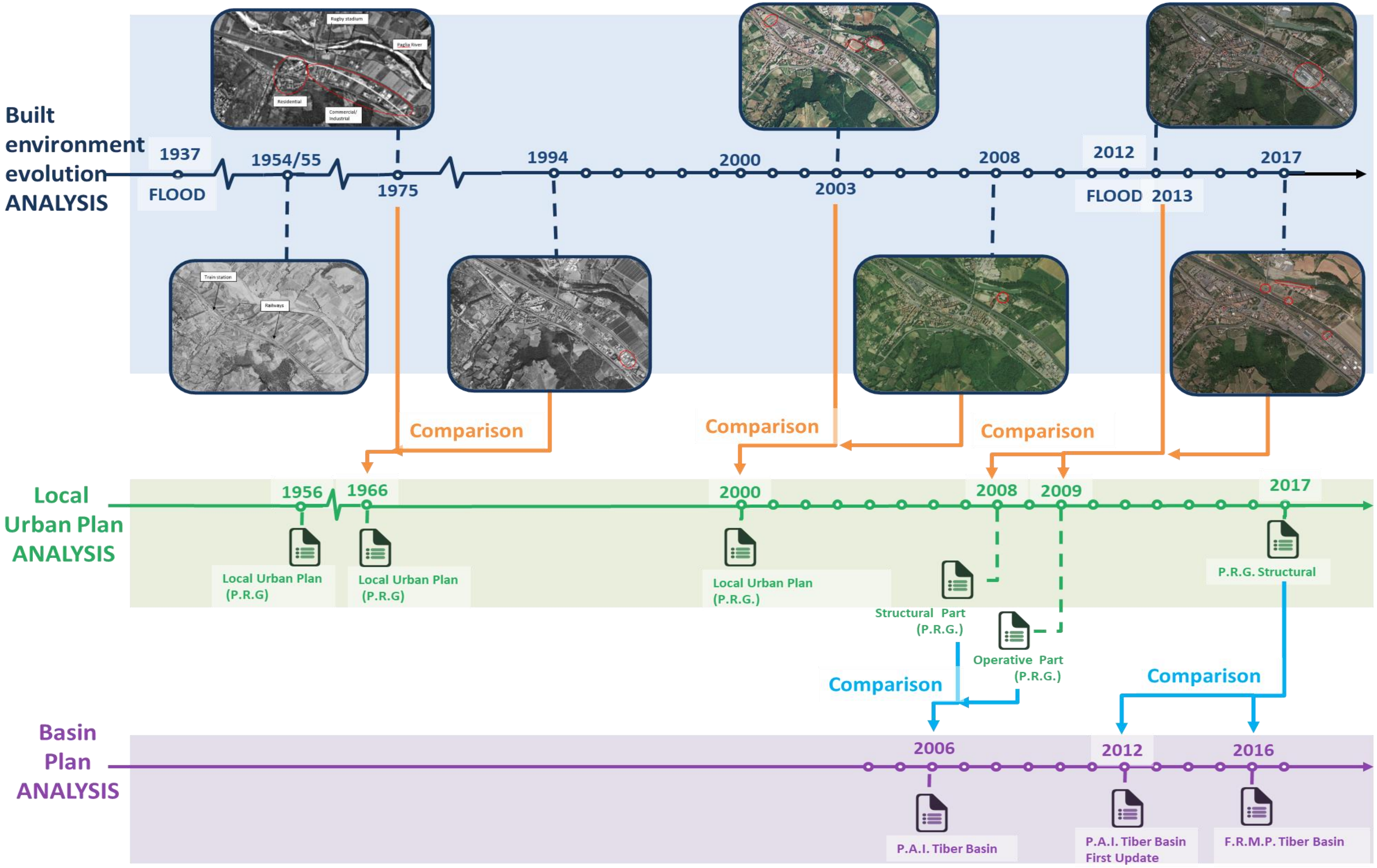


Figure 12 Method for Investigating Spatial Planning as a Risk Driver (source: author)

For the *Local Urban Plan Analysis,* both historic and in force local urban plans are collected and organised chronologically, as shown in the central timeline in Figure 12. The land-use maps present in the plans are assembled chronologically and compared. Norms associated to the land-use maps concerning admitted uses and transformations are also studied. For each plan, the analysis also interrogates whether flood hazard and risk are considered or mentioned inside the documents, and if so, how. In addition, it compares each local plan with its predecessor to understand (by locality) if (i) there are land-use changes or transformations in flood-prone areas; (ii) if there are new zones foreseen in the plan to be developed in flood-prone areas. These "flood prone areas" correspond to the ones defined by the latest basin plan, i.e. the basin plan in force at the date of the analysis. Results of the analysis are synthesised on a table, like Table 14.

Table 14 Presentation of results of the Local Urban Plan Analysis (source: author).

Local Urban Plan	**Year**	**Locality**	**Flood hazard/risk considered**		**Land use / Future uses**	**Land use changes**
			(Yes/No)	**How?**		

The *Basin Plan Analysis* examines the evolution of Basin Plans, shown in the last timeline in Figure 12. The analysis focuses on the evolution of flood hazard and risk maps and related norms. It also aims to understand if these norms limit development in flood-prone areas. Specific questions are proposed to guide the analysis, as presented in Table 15. Some of these questions are general to the plan and some are relative to the area under analysis, specified as a locality.

Table 15 Presentation of results of the Basin Plan Analysis (source: author).

Basin Plan	**Year**	**Questions**	**Locality**	
			Locality name	
			Yes/No	**Comments**
Basin plan name		Are flood hazard maps present for the locality?		
		Are flood risk maps present for the locality?		
		Does the plan limit development in flood-prone areas?		
		Did flood risk maps change from one plan to the other? How?		
		Did the norms that address development change from one plan to the other? How?		

After these analyses are finished, they are combined, as shown in Figure 12, through two different comparisons. In the first comparison (indicated with orange lines), identified changes in the built environment in each year are compared with the scenarios defined in the Local Urban Plan in force at that year (i.e. land use maps with current and future uses). This aims to understand whether changes in the built environment were foreseen in local plans. These comparisons are performed in sequence, following changes in time in both the plans and the built environment. For example, in Figure 12 the orthophoto from the *Analysis of the Evolution of the Built Environment* of 1975 is compared with the land use map from the 1966 Local Urban Plan (i.e. plan in force in 1975), from the *Local Urban Plan Analysis*.

In the second comparison (indicated with turquoise lines), Local Urban Plans are contrasted with Basin Plans in force. Land use maps from Local Plans are overlapped with flood hazard and risk maps to understand whether they comply with the norms of the Basin Plan in force at that time. In addition, norms of the Basin Plans are compared with regulations present in local plans. These two kinds of comparisons are performed in parallel in order to investigate as well, whether urban development complied with the norms set in Basin Plans. These questions are synthesised in Table 16 and answered by locality. Figure 12 shows for example how the Local Urban Plan of 2009 is compared with the Basin Plan in force at that time, i.e. the 2006 Basin Plan.

Table 16 Questions to answer in comparisons between the three analyses (source: author).

Questions	**Locality**
	Locality name
Were changes in the built environment foreseen in local urban plans?	
Do Local Urban Plans comply with the norms of the Basin Plans?	
Has urban development complied with Basin Plans?	

4.5 REVISED NEW METHOD FOR DISASTER FORENSIC INVESTIGATION

As already mentioned, the development of the new Disaster Forensic Investigation method is an iterative process. This method was improved after its application to the case studies, culminating in the proposal of a revised method for disaster forensic investigation for future studies. This revised new method for Disaster Forensic Investigation is presented in Chapter 7.

4.6 CASE STUDIES

The case studies in this research focus on the study of towns before and after one or more flood events. Two main case studies are selected according to the criteria explained next. Then the data within the case studies are collected and analysed. The methods for case study data collection and analysis are presented next.

4.6.1 Case studies selection

The main requirement for the case studies selection is that they are towns or cities that were at least flooded once. In addition, the case studies require also the presence of post-flood damage data, i.e. the collection of data on flood damages ex-post. These data are needed to be able to apply the newly developed Disaster Forensic Investigation method. The case studies are then selected from cases where damage data were specifically collected after the flood for at least one damaged sector. Furthermore, to explore how disaster forensic investigation can enhance the knowledge base used in the development of plans in flood-prone areas at different spatial levels, the selection criteria considers also different scales. This is achieved through the selection of one case study that focuses on the main town, and on another one that includes different towns in the same region.

As this PhD dissertation is associated with the European project IDEA (Improving Damage assessments to Enhance cost-benefit Analyses), the case studies are selected within Europe. One of the case studies is selected from the case studies in the project that fulfilled the selection requirements. Different cases were considered from which two main case studies were selected, namely:

- The town of Grimma, in the State of Saxony, Germany, before and after the 2002 and 2013 floods.
- The localities of Ponticelli, in Citta' della Pieve and Orvieto Scalo and Ciconia, in Orvieto, in the Umbria Region, Italy, before and after the 2012 flood.

To summarise, the selected case studies comply with the following criteria:

- Being a European town that was flooded
- Flood damage data was collected ex-post
- Different scales considered (Local/Regional)

4.6.2 Case study data collection

The data collected in the case studies are both quantitative and qualitative and from different sources. These data sources include amongst others direct observations, interviews performed by other researchers, archival records, official documents, newspaper articles, reports, academic papers, etc.

Regarding the post-flood damage data, the methods for data collection varied from one case study to the other. In the Grimma case study, the post-flood damage data of the residential sector are collected from existent structured telephone interviews with affected residents. These interviews were conducted by other researchers for collecting data for risk modelling purposes. Instead, in the Umbria case study, the post-flood damage data of the industrial and commercial sectors are collected in three ways. First, from official documents of forms distributed by authorities to affected enterprises after the flood (for compensation purposes). Second, from national and regional decrees establishing the compensation amounts for affected enterprises. Third, from direct observations, surveys and analyses carried out by the Politecnico group in the IDEA project. The data collected with this last method proved to be very valuable because it includes information that otherwise would not have been available. The data collected, and their sources are described in more next detail, for each case study.

4.6.2.1 Case Study 1: Grimma, Saxony, Germany

My three-months research stay at the Helmholtz-Centre for Environmental Research GmbH (UFZ) in Leipzig allowed me to visit the town of Grimma and to collect data through direct observations. It also allowed me to collect data from multiple sources, including documents from past projects developed at the UFZ. The data collected in this case study are both qualitative and quantitative. A large variety of sources of evidence is used within the Grimma case study. They include documents of a different kind, archival records, direct observations, interviews of different types, satellite imagery and maps. They are described in the next paragraphs.

Direct Observations

The direct observations focused on Grimma's physical environment and the data were collected by the author through fieldwork on June the 25th, 2017 (Table 17). Observational data were collected with field notes, photographs and by measuring the height of the remembrance plaques, indicating the floods' water depth.

Table 17 Direct observations in Grimma case study data collection (source: author).

Direct observations	Data collection method	Date of fieldwork
Grimma's physical environment	Field notes	June 25, 2017
	Photos	
	Measurements with measuring tape	

Documents

The documents in Grimma case study data collection are of different kind, i.e. theses, peer-reviewed papers, reports, e-mails, plans and newspaper articles. Table 18 presents the collected documents in terms of title, type, date and author. Table 19 shows the newspaper articles collected, including the newspaper's name, date, date of access and website.

Table 18 Documents in Grimma case study data collection (source: author).

Document title	Document Type	Date	Author
Hochwasser & Eigenvorsorge – Untersuchung von Einflussfaktoren persönlicher Schutzmaßnahmen	Master thesis	2010	Siedschlag
Economic evaluation of structural and non-structural flood risk management measures: examples from the Mulde River	Peer-reviewed paper	2011	Meyer et al.
Flood damage and influencing factors: New insights from the August 2002 flood in Germany	Peer-reviewed paper	2005	Thieken et al.
CEDIM Annual Research Report 2012	Report	2013	CEDIM
Systematisation, evaluation and context conditions of structural and non-structural measures for flood risk reduction.	Report	2008	Schanze et al.
Die größten Hochwasser im Einzugsgebiet der Mulde im meteorologisch-hydrologischen Vergleich	Report	2016	Schumann et al.

Document title	**Document Type**	**Date**	**Author**
CRUE Final Report FREEMAN- Flood Resilience Enhancement and Management: a pilot study in Flanders, Germany and Italy	Report	2011	Uyttendaele et al.
Risk Governance and Natural Hazards, WP 2 report	Report	2010	Walker et al.
Der Wiederaufbau im Freistaat Sachsen nach dem, Hochwasser im Juni 2013	Report	2013	Free State of Saxony
Hochwasserschutz Grimma, Maßnahmekonzept	Report	2006	Landestalsperrenverwaltung des Freistaates Sachsen
Personal communications with Grimma Municipality	E-mail	2017	

Table 19 Newspaper articles in Grimma case study data collection (source: author).

Document Type	**Newspaper name**	**Date**	**Access date**	**Website**
Newspaper article	Bild	June 6, 2013	June 2017	www.bild.de/regional/leipzig/hochwasser-grimma-zentrum-evakuiert-306555130.bild.html
Newspaper article	CNN	August 20, 2002	June 2017	www.edition.cnn.com/2002/WORLD/europe/08/20/europe.floods.holmes.otsc/
Newspaper article	Colditzer-tageblatt	2013	June 2017	www.colditzer-tageblatt.de/hochwasser-2013-muldental-grimma-colditz-doebeln-sachsen-bilder-video/197-hochwasser-2013-im-muldental-bilder-tag-3.html
Newspaper article	DW	June 6, 2013	July 2017	www.dw.com/en/german-town-hit-by-two-floods-of-the-century/a-16864221
Newspaper article	LVZ	June 14, 2013	June 2017	www.lvz.de/Specials/Themenspecials?Hochwasser-in-Sachsen/Hochwasser-in-der-REgion/Grimma-Oberbuergermeister
Newspaper article	LVZ	June 1, 2017	June 2017	www.lvz.de/Region/Grimma/Flutmauer-in-Grimma-soll-2018-funktionsfaehig-sein
Newspaper article	n-tv	June 3, 2013	October 2017	http://www.n-tv.de/panorama/Es-ist-eine-Katastrophe-article10751551.html
Newspaper article	Spiegel	June 4, 2013	June 2017	www.spiegel.de/panorama/hochwasser-in-grimma-wieso-die-schutzmauer-nicht-fertig-wurde-a-903738.html
Newspaper article	Welt	June 3, 2013	June 2017	www.welt.de/vermischtes/article116751245/Elbe-steigt-in-Dresden-ueber-die-7-Meter-Marke.html

Archival Records

The collected archival records regard data on the population and on housing prices. The population inflows and outflows in the centre of Grimma and in the total municipality, as well as the population of the centre by year of birth, were collected from the municipal registry of residents of Grimma. Data on the prices of houses sold in Grimma inside and outside the flood-prone area were collected from the archives of the Expert Committee for property values in Leipzig ("Gutachterausschuss für Grundstückswerte im Landkreis Leipzig"). Table 20 presents the records specifying the records' year and the date of data collection.

Table 20 Archival records in Grimma case study data collection (source: author).

Archive name	**Records**	**Year of records**	**Date of collection**
Grimma Municipal registry of residents	Population inflows to Grimma centre	2009 to 2015	July 2017
	Population outflows from Grimma centre	2009 to 2015	July 2017
	Population inflows to Grimma municipality	2009 to 2015	July 2017
	Population outflows from Grimma municipality	2009 to 2015	July 2017
	Population by year of birth in inner Grimma	2001 to 2015	July 2017
EXPERT COMMITTEE for property values in the district of Leipzig	Price of houses sold in the flood-prone area in Grimma	2012 to 2016	July 2017 and January 2018
	Price of houses sold outside the flood-prone area in Grimma	2009 to 2016	July 2017 and January 2018

Satellite Images, Maps and Websites

All the satellite images were collected from Google Maps and Google Earth in 2017. These images were taken in different years and they all cover Grimma's city centre (Table 21). Collected maps are described in Table 22. Last, several websites were consulted for collecting data on hydraulic construction projects, early warning systems, city characteristics, etc. (Table 23).

Table 21 Satellite images collected in Grimma case study (source: author).

Satellite image source	**Description**	**Image Year**	**Year of collection**
Google Maps	Satellite image of Grimma centre	2017	2017
Google Earth	Satellite image of Grimma centre	2000	2017
Google Earth	Satellite image of Grimma centre	2009	2017
Google Earth	Satellite image of Grimma centre	2013	2017

Table 22 Maps collected in Grimma case study (source: author).

Map source	**Description**	**Map year**	**Year of collection**
Elbe Atlas	Flood hazard map	2012	2017
Google Maps	Restaurants and bars map	2017	2017
Grimma municipality	Schools and kindergartens in Grimma	2017	2017
Saxony State Office for Environment, Agriculture and Geology	Flooded areas in 2002 and 2013 (shapefile)	N/A	2017
floodmap.net	Elevation map of the town of Grimma	N/A	2017
Flood-ERA project	Mulde River catchment elevation map	N/A	2017

Table 23 Websites in Grimma case study data collection (source: author).

Website name	**Website address**	**Access date**
Grimma Municipality	www.stadt-grimma.de, hochwasserschutz-grimma.de	September 2017
Grimma Museum	www.museum-grimma.de/index.php/bilderflut-flutbilder.html	June 2017
Saxony State Office for Environment, Agriculture and Geology (LfULG)	www.umwelt.sachsen.de/umwelt/wasser/10002.htm?data=hw2002	September 2017
Saxony Police	www.polizei.sachsen.de/de/14607.htm	June 2017

Interviews from other research projects

Different kinds of interviews are collected from past projects, conducted by other researchers. The collected interviews are of two types (Table 24): semi-structured and structured. In the first case, they concern government officials, including the mayor. In the second case, they are computer-aided telephone interviews with affected residents after the 2002 and 2013 flood in Grimma. These interviews are explained in more detail next.

Table 24 Interviews in Grimma case study data collection (source: author).

Interview type	**Description**	**Interviewee(s)**	**Interviewee(s) role**	**Date of interview(s)**	**Interview(s) source**
Semi-structured	Telephone interview	Mr Berger	Mayor	January 10, 2006	Flood-ERA project
Semi-structured	Telephone interview	Ms Guhlemann	Urban planning officer	December 20, 2005	Flood-ERA project
Semi-structured	Telephone interview	Mr Hahn	Head of Water Authority	December 20, 2005	Flood-ERA project
Structured	Computer-Aided Telephone Interview (CATI)	Grimma affected residents by the 2002 flood	Household owner/renter	April and May 2003	The University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung
Structured	Computer-aided telephone interview (CATI)	Grimma affected residents by the 2002 flood	Household owner/renter	April 2014	The University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung

Structured interviews: Affected residents in the 2002 flood event

Flood damage and other related data of the residential sector from the 2002 flood event were provided by the University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung. These data were collected through computer-aided interviews (CATI) among households in the flooded area in the aftermath of the 2002 flood event, between April and May 2003. The objective of the survey was to investigate damage influencing factors (Thieken et al., 2005), namely for research purposes.

Available data does not include all the households in the flooded area in Grimma, but it represents a subset of 21. Before conducting the interviews in 2003, a sample of affected households was defined by first retrieving a list of the inundated streets through an in-depth analysis of information from the affected municipalities, flooded areas, official reports, etc. Then, telephone numbers of residents of households in the identified flooded streets were recovered from the telephone registry, and households were randomly selected, including at least one building per flooded street.

The questionnaire contained around 180 questions, addressing the following topics:

- Flood characteristics
- Flood warning
- Emergency measures
- Evacuation
- Damage to building and contents
- Characteristics of building and contents
- Recovery
- Precautionary measures
- Flood experience
- Socio-economic variables

Structured interviews: Affected residents in the 2013 flood event

Flood damage and other related data of the residential sector from the 2013 flood event were provided by the University of Potsdam, German Research Centre for Geosciences and Deutsche Rückversicherung. These data were collected through computer-aided interviews (CATI) among households in the flooded area, 9 months after the 2013 flood event. The main objective of the data collection was to investigate how losses are influenced by other factors (Thieken et al., 2016a).

Available data does not include all the households in the flooded area in Grimma, but it represents a subset of 41. The sampling method used for conducting the interviews in 2013 differs from the one of 2002. Lists of flooded streets were made based on flood reports, information from municipalities and flooded areas. Telephone numbers were then retrieved from the telephone directory and all potentially "affected residents" were contacted. However, only "affected residents" were interviewed, defined in the survey as residents of a "household that had suffered (financial) flood damage in May or June 2013" (Thieken et al., 2016a).

It is important to note that even if all the retrieved telephone numbers were contacted, as opposed to the 2002 flood event, these data do not contain all the damaged households, but only those households that were damaged and were listed in the telephone registry. Nowadays, mobile phones are replacing landline phones, especially between young generations, and given that the official telephone registry contains only landline telephone numbers, not all the residents are listed.

The main topics addressed in the interview were mostly the same as in the interviews in 2002. The main difference with respect to the 2002 event questionnaire is the inclusion of the effects of the flood on health and wellbeing. There are some other differences regarding the questions that were asked in each topic in terms of content. This proved to be an important aspect when comparing the results of the analysis of the two events.

4.6.2.2 Case Study 2: Umbria Region, Italy

The data collected in this case study are both qualitative and quantitative. Different sources of evidence are used within the Umbria case study.

Direct observations and surveys

The Politecnico di Milano group in the IDEA project collected data on flood damages to affected enterprises in Orvieto Scalo in two occasions following the flood in November 2012. The method for data collection is called RISPOSTA (Reliable InStruments for POST event damage Assessment), a new procedure for the collection of damage data at the local scale, after flood events, developed by researchers of the Politecnico di Milano with the Umbria Region Civil Protection. It consists of direct surveys in the field using different forms. These forms were developed for both residential and industrial/commercial activities and allow to collect different kinds of information. These include data such as the characteristics of the flood event (duration, water depth), the damaged building description, the damages to the building, the damages to the building's contents and indirect damages such as the number of days of inactivity. A detailed description of the RISPOSTA procedure and the surveys are provided in Molinari et al. (2014) and in Berni et al. (2017). In November 2012, 5 economic activities were surveyed thoroughly in Orvieto Scalo. In contrast in October 2013, 6 activities were assessed.

Table 25 Data collection with surveys on damaged industrial and commercial activities (source: author).

Surveys	Area	Data collection method	Date
Damaged industrial and commercial activities	Orvieto Scalo, Orvieto	RISPOSTA procedure	Nov-12
Damaged industrial and commercial activities	Orvieto Scalo, Orvieto	RISPOSTA procedure	Oct-13

Documents

The documents in the Umbria case study data collection are of different kinds. They include spatial plans, reports, hydraulic studies and decrees. The report by Ballio et al. (2013) includes the analyses developed by the group of Politecnico on the 2012 flood event. They are listed in Table 26.

Table 26 Documents in the Umbria case study data collection (source: author).

Document title	**Document Type**	**Date**	**Author**
Lo Scenario di Danno in Seguito all'Alluvione di Novembre 2012 nella Regione Umbria	Report	2013	Ballio et al.
Event Report of the 11-14 November flood	Report	2012	Centro Funzionale Regione Umbria
Scheda segnalazione danni, Umbria Region (Form for damage reporting)	Official documents	2012	Affected owners of economic activities in Orvieto Municipality
Tiber Basin Plans	Basin Plan	1999, 2006, 2008, 2012	Tiber Basin Authority
Tiber Flood Risk Management Plan	Basin Plan	2016	Tiber Basin Authority
Local Urban Plans Citta' della Pieve (P.R.G. and Variants)	Urban Plan	1998, 2000, 2002, 2011, 2013, 2016, 2017	Citta' della Pieve Municipality
Local Urban Plans Orvieto (P.R.G.)	Urban Plan	1966, 2009	Orvieto Municipality
Ricostruzione delle aree allagate per il torrente Chiani e per il fiume Nestore	Hydraulic study	2013	Barbetta et al. (CNR-Irpi)
Analisi idraulica e idrologica della piena del fiume Paglia nelle zone di Orvieto Scalo e di Ciconia e scenario di esondabilità	Hydraulic study	2013	Ramazzina
DFR/08/2013, n.3 "Provisions for the granting of subsidies to non-agricultural enterprises damaged by the flood events"	Decree	2013	Umbria Region
DFR 24/12/2013	Decree	2013	Umbria Region
DFR 19/02/2015	Decree	2015	Umbria Region

Orthophotos and Satellite images

Both orthophotos and satellite images are collected for the Umbria case study from different sources, listed in Table 27.

Table 27 Orthophotos and satellite images collected in the Umbria case study (source: author).

Orthophoto Satellite image source	**Description**	**Image Year**	**Year of collection**	**Website**
Umbria Region	Orthophoto of Ponticelli	1954/ 1955	2017	http://siat.regione.umbria.it/paesaggineltempo/
		1997	2017	
		2000	2017	
		2005	2018	
		2009	2018	
	Orthophoto of Orvieto Scalo/Ciconia	1954/ 1955	2018	
		2000	2018	
		2008	2018	
USGS, Declassified data 2002	Orthophoto of Ponticelli	1980	2017	https://earthexplorer.usgs.gov/
	Orthophoto of Orvieto Scalo/Ciconia	1975	2017	
		1980	2017	
Ministero dell'Ambiente	Orthophoto of Ponticelli	1988	2017	www.pcn.minambiente.it/viewer/
		1994	2017	
	Orthophoto Orvieto Scalo/Ciconia	1988	2018	
		1994	2018	
		2006	2018	
		2009	2018	
Google Earth	Satellite image of Ponticelli	2003	2018	-
		2013	2018	
		2017	2018	
	Satellite image of Orvieto Scalo/Ciconia	2013	2018	
		2017	2018	

4.6.3 Case study data analysis

The new method for Disaster Forensic Investigation developed in the context of this Thesis is used for data analysis in the case studies. The new method is applied to Grimma, for the 2002 and 2013 floods. However, the Grimma case study does not permit to apply the new Disaster Forensic Investigation method entirely. The investigation of the role of spatial planning in shaping disaster risk cannot be accomplished because the town lacks spatial plans, both currently and historically. In the Umbria case study, the new method for Disaster Forensic Investigation is applied in its entirety, including the application of the method for investigating spatial planning role in shaping disaster risk.

Besides the Disaster Forensic Investigation method, the post-flood damage data collection processes in the case studies are assessed according to their fitness for forensic investigation. This assessment is done through the evaluation of the quality of the collected data. As Wand & Wang (1996) state, data quality is a "multi-dimensional" concept, with no rigorously defined dimensions in the literature.

However, there are different dimensions that are generally used to assess data quality. These assessments can be task-independent or task-dependent, which means that data are evaluated considering the application at hand (Pipino et al., 2002). It is this task-dependent assessment that is useful to evaluate the quality of the post-flood damage data collected for the specific purpose of forensic investigation. However, other task-independent data quality dimensions are also relevant for assessing the data collection process, for example, if the data collected is free-of-error (correct and reliable) or if they are objective. Therefore, both task-dependent and task-independent quality dimensions are selected for the assessment following (Wand & Wang, 1996) and (Pipino et al., 2002), shown in Table 28. They are classified according to the characteristic they represent, i.e. soundness, usability and usefulness.

Table 28 Data quality dimensions, adapted from (Pipino et al., 2002) and (Wand & Wang, 1996).

Characteristic	**Category**	**Dimension**	**Definition**
Soundness	Task-dependent	Completeness	The extent to which data is not missing and is of sufficient breadth and depth for the task at hand.
	Task-independent	Free-of-Error	The extent to which data is correct and reliable.
		Consistent representation	The extent to which data is presented in the same format.
Usability	Task-independent	Accessibility	The extent to which data is available, or easily and quickly retrievable.
Usefulness	Task-dependent	Appropriate amount of data	The extent to which the volume of data is appropriate for the task at hand.
	Task-independent	Objectivity	The extent to which data is unbiased, unprejudiced, and impartial.
		Interpretability	The extent to which data is in appropriate languages, symbols, and units, and the definitions are clear.

4.7 STUDY ETHICS

Data on damages at the local level (i.e. at object level such as a household or an industry) are generally collected in conjunction with sensitive data such as the name and contact details of the affected person (resident or owner) and the address of the affected objects. In order to protect this information, data on the address and ownership of households, commercial activities and industries in the case studies are not included in the analysis, neither are represented in maps to ensure data privacy.

5 CASE STUDY 1: GRIMMA, SAXONY, GERMANY

The city of Grimma in Saxony, Germany (before and after the 2002 and 2013 floods) is the case under study. The new Disaster Forensic Investigation method is applied in the case study analysis, as developed in Chapter 4, for the 2002 and 2013 flood events in Grimma. The case study analysis is presented following the structure of the new Disaster Forensic Investigation method starting from a brief introduction.

5.1 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 13).

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.

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.

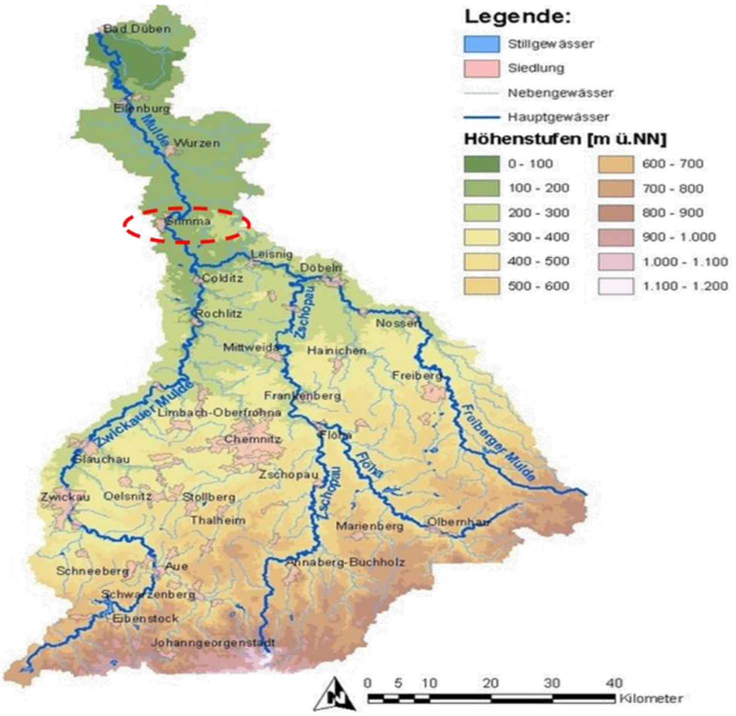


Figure 13 Mulde River catchment (source: Flood-ERA project)

Figure 14 Grimma town centre (source: Grimma.de)

Figure 15 Grimma town centre in 2017 (source: author).

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).

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

Figure 19 Grimma city hall during the flood in 2013 (source: Welt.de, dpa / Jens Wolf).

Figure 16 Grimma city hall during flood in 2002 (source: Welt.de, dpa).

Figure 17 Rescue during the 2013 flood (source: Welt.de, dpa/Jan Woitas).

Figure 18 Rescue during the 2002 flood (source: Welt.de, pa/ZB).

5.2 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.).

5.2.1 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 29).

Table 29 Indicators table for the hazard event (source: author).

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

5.2.1.1 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).

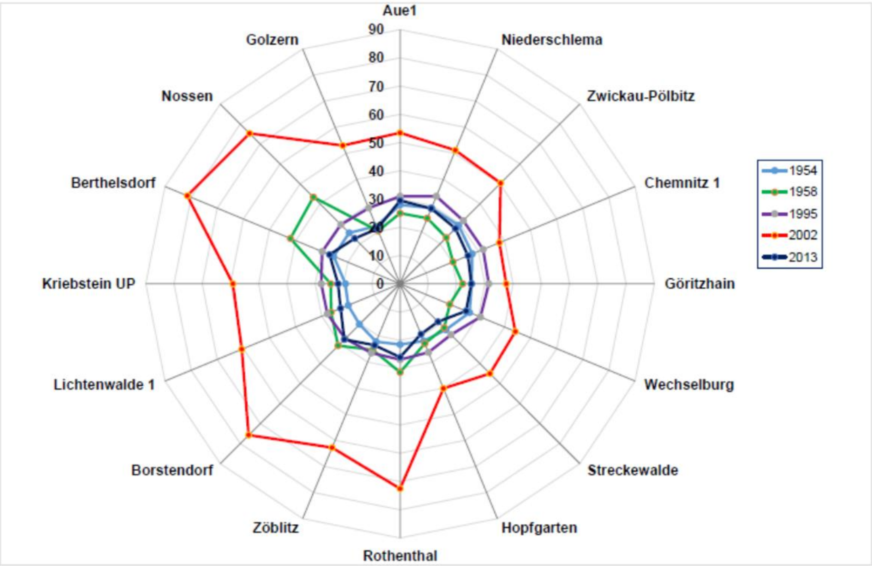


Figure 20 6-hour precipitation [mm] in pluviometers in Saxony in the Mulde catchment for historical events (source: Schumann et al., 2016)

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 21 (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 the 11th of August (ibid.). 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.

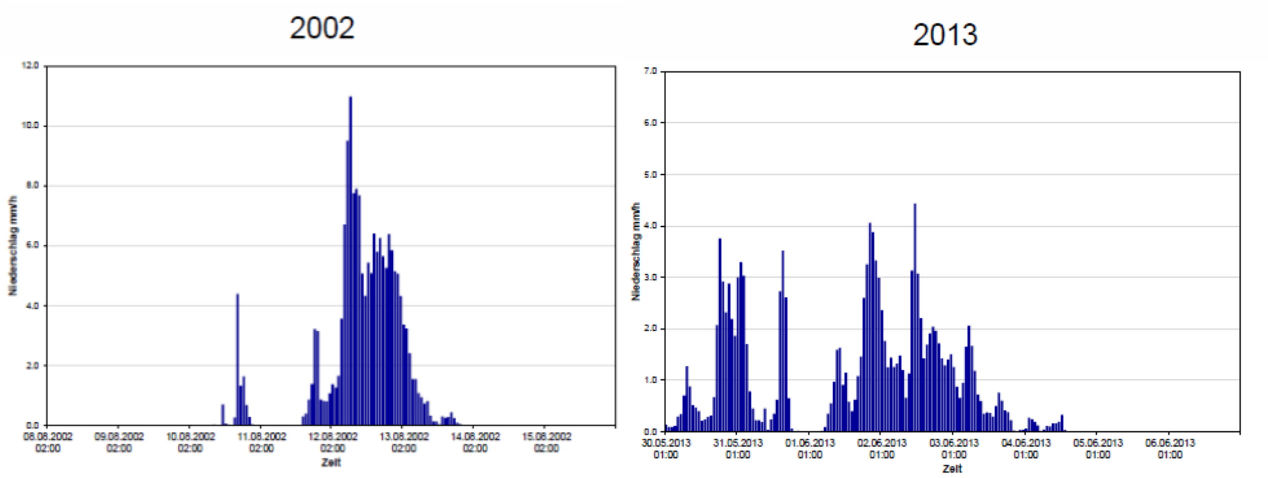


Figure 21 Rainfall intensity [mm/h] in time for the 2013 and 2002 flood events in Pegel Bad Düben 1/Vereinigte Mulde gaging station (source: Schumann et al., 2016)

5.2.1.2 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, 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 by Schumann et al. (2016). 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, both events of 2002 and 2013 were characterized by high pre-humidity (Schumann et al., 2016).

5.2.1.3 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 m³/s, while in 2013, 2040 m³/s. Figure 22 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 in 2013, with a ratio that varies from 0.6 to 4.3.

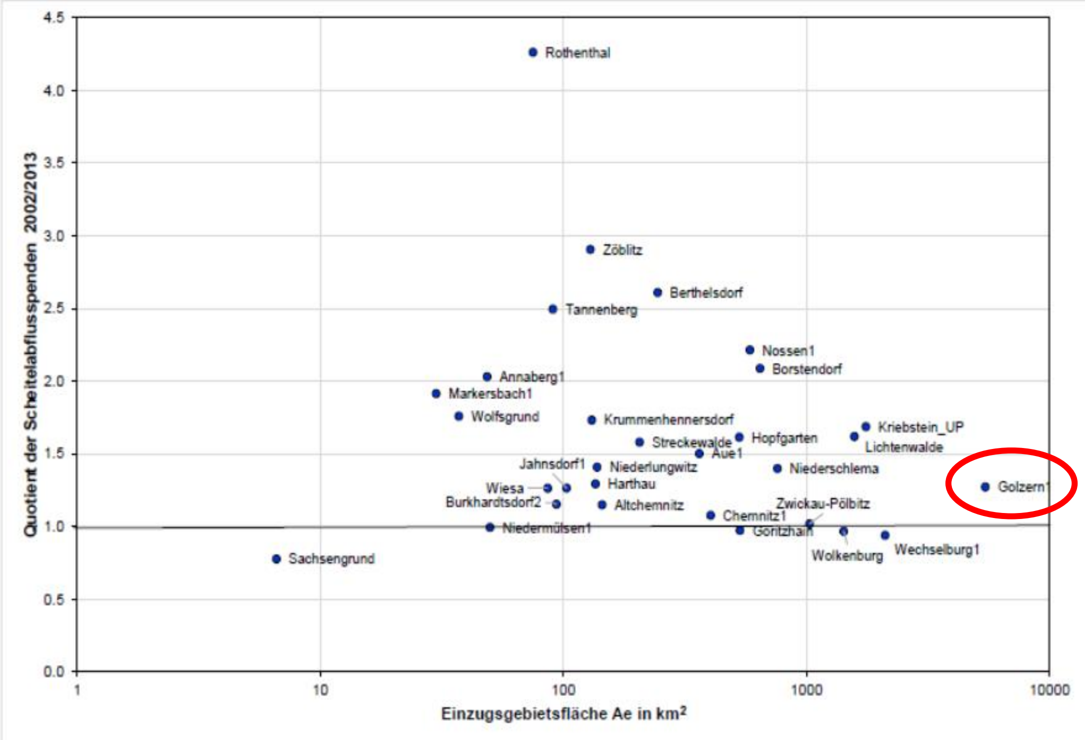


Figure 22 Ratio of peak discharge in 2002 and 2013 in different gaging stations (source: Schumann et al., 2016)

5.2.1.4 Water depth, velocity and contaminants

Available data regarding water depth corresponds to the data collected at a household level, through telephone interviews with residents. Different statistics were calculated from the samples, i.e. statistical mean, median, 25th and 75th percentile, all represented in Figure 23. 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.

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).

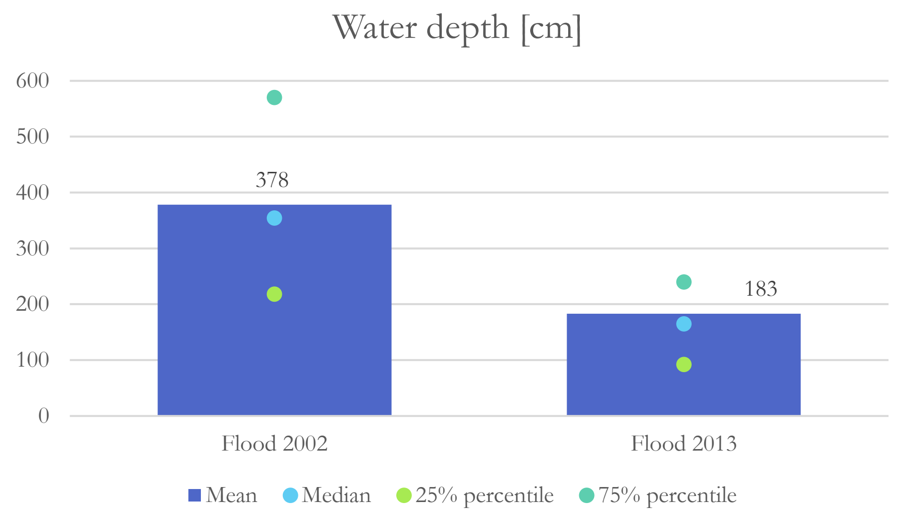


Figure 23 Water depth [cm] in 2002 and 2013 floods (source: author).

5.2.1.5 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 24), 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.

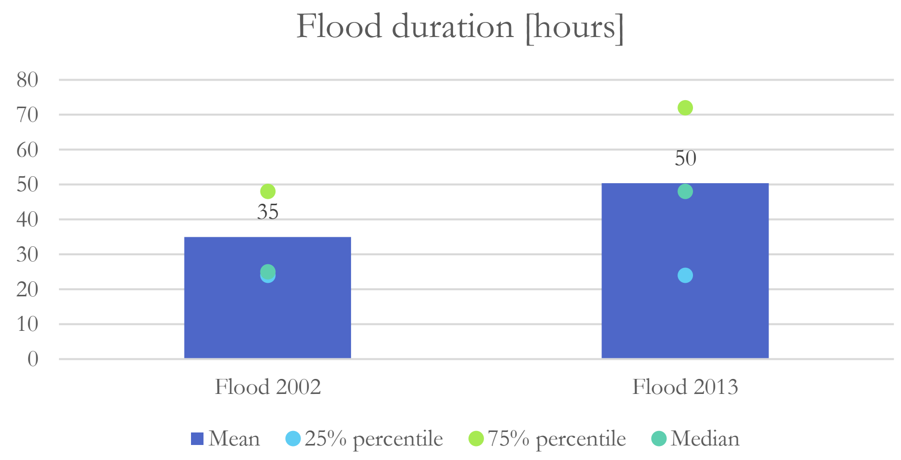
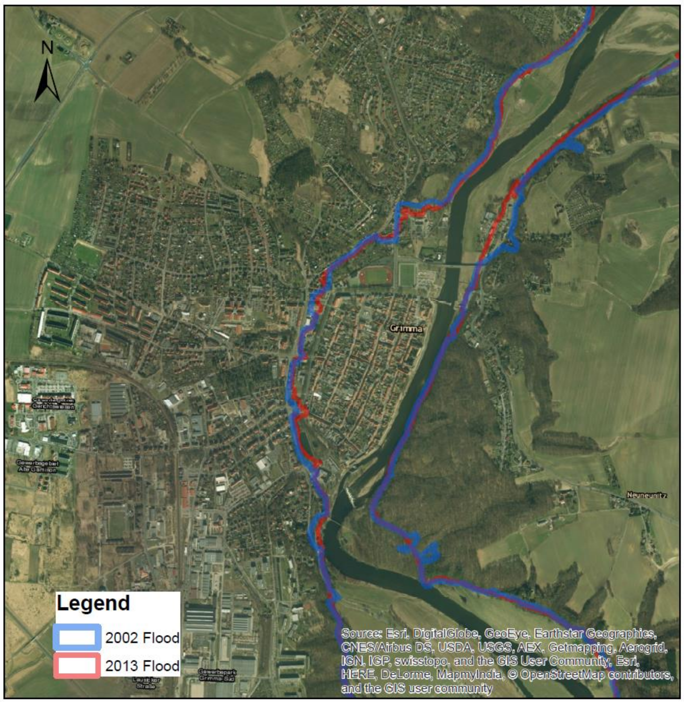


Figure 24 Flood duration [hours] at households for the 2002 and 2013 floods (source: author).

5.2.1.6 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 25) shows that the flooded area in 2002 is slightly bigger than in 2013 for the town of Grimma.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 25 Map of the flooded areas in 2002 and 2013 (source: author, based on data from the Saxony State Office for Environment, Agriculture and Geology, 2017).

5.2.2 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 27).

Figure 26 Pictures of the 1897 and 1954 floods in Grimma (source: Landestalsperrenverwaltung des Freistaates Sachsen, 2006).

Figure 27 shows the most important historic floods and their respective water depths in Grimma, as represented in the Großmühle (large mill). Moreover, Table 30 shows the water level in the Mulde River in Grimma for some important flood events.

Table 30 Water level in the Mulde River in Grimma during some flood events (source: 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

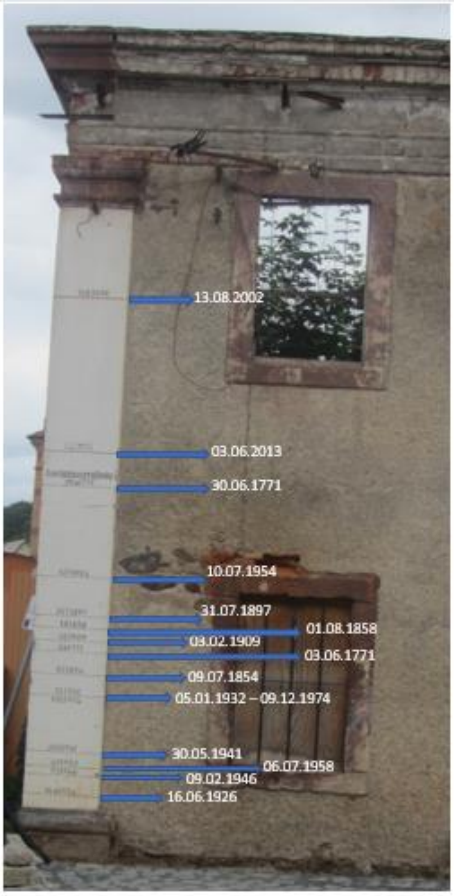


Figure 27 Historic flood levels in the Großmühle (large mill) in Grimma (source: author).

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 28. This explains why floods are always confined to the area of the city centre.

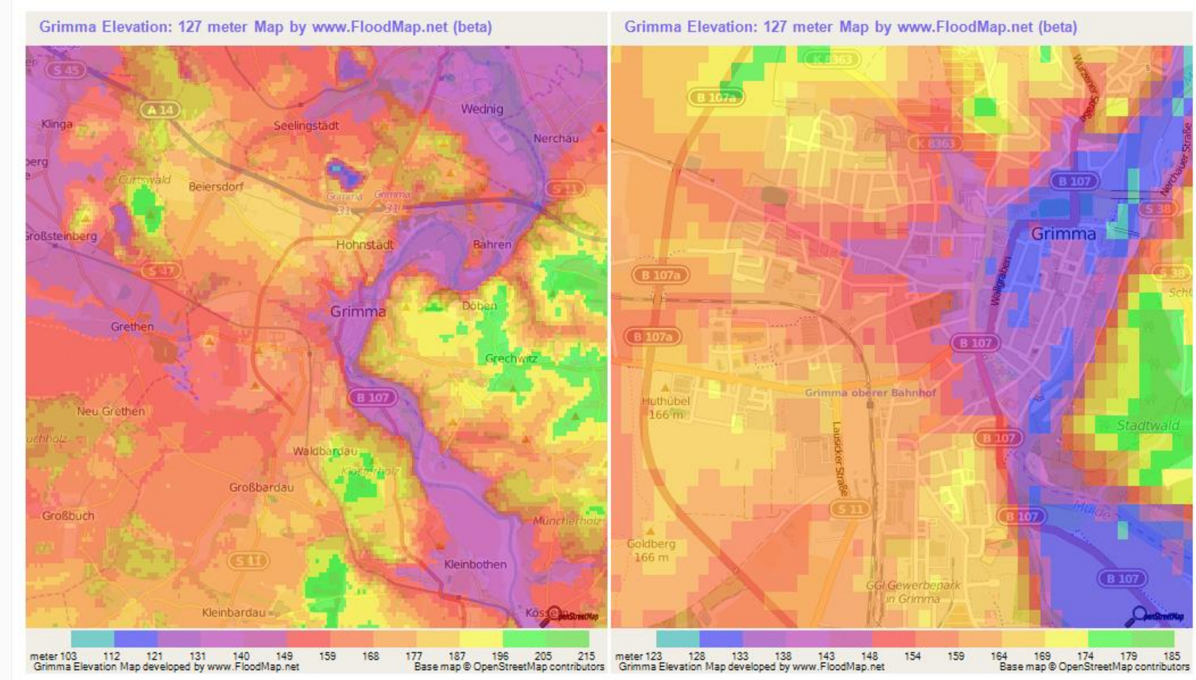


Figure 28 Elevation map of the town of Grimma

(source: http://www.floodmap.net/Elevation/ElevationMap/?gi=2917325).

5.3 SECTION II: SOCIO-ECONOMIC DISASTER LANDSCAPE

5.3.1 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, wherein 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 (Figure 29). 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).

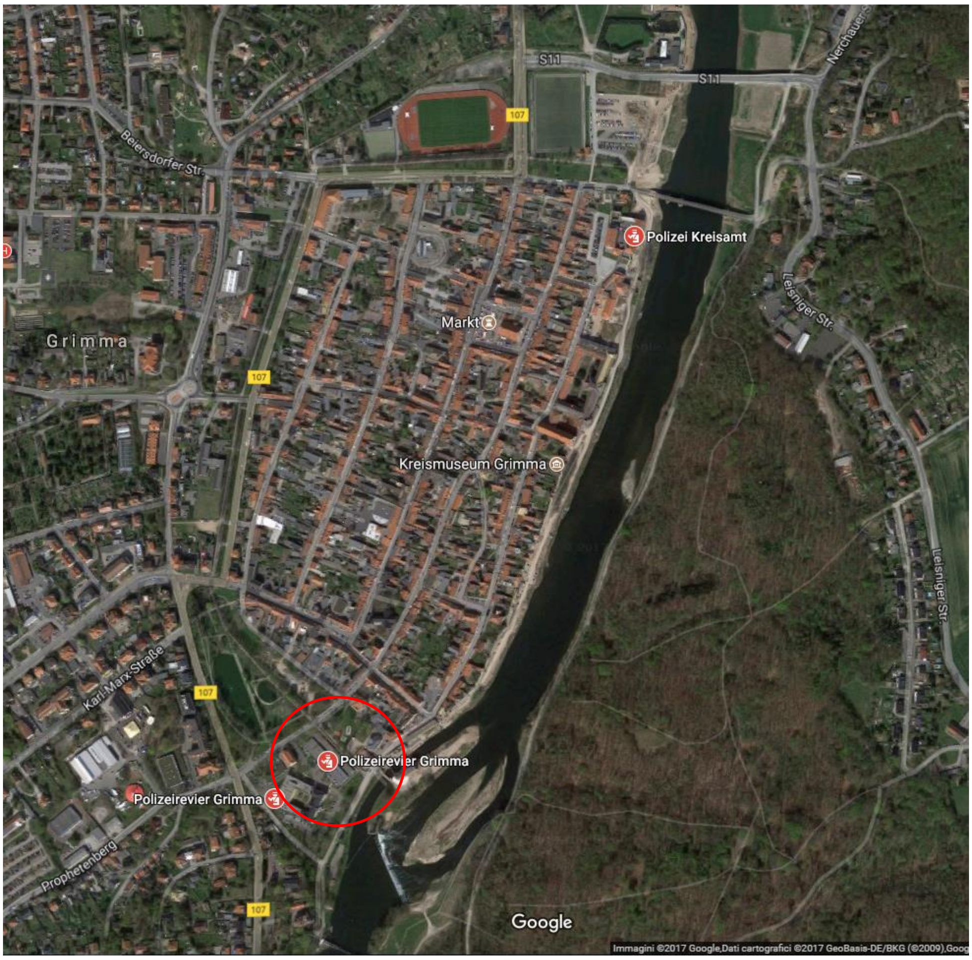


Figure 29 New police station in Grimma town centre, indicated with a red circle (source: Google maps)

Figure 30 One of the buildings of the new police station in Grimma (source: https://www.polizei.sachsen.de/de/14607.htm)

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

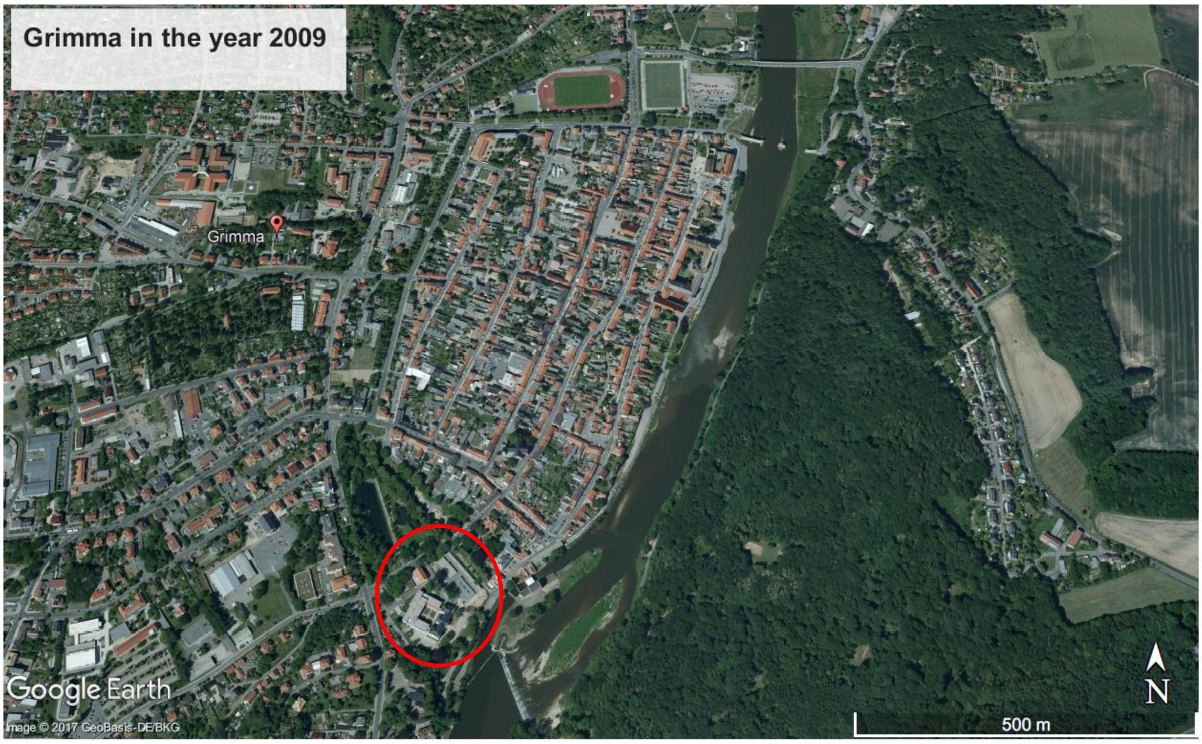


Figure 32 Satellite image of Grimma in 31-12-2009 (source: Google Earth2017)

Figure 33 Satellite image of Grimma in 30-09-2013 (source: 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 31, Figure 32, Figure 33), 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 on August 20th, 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 34). Moreover, other touristic attractions in the centre include the Kreismuseum, the Frauenkirche church and other historic buildings.

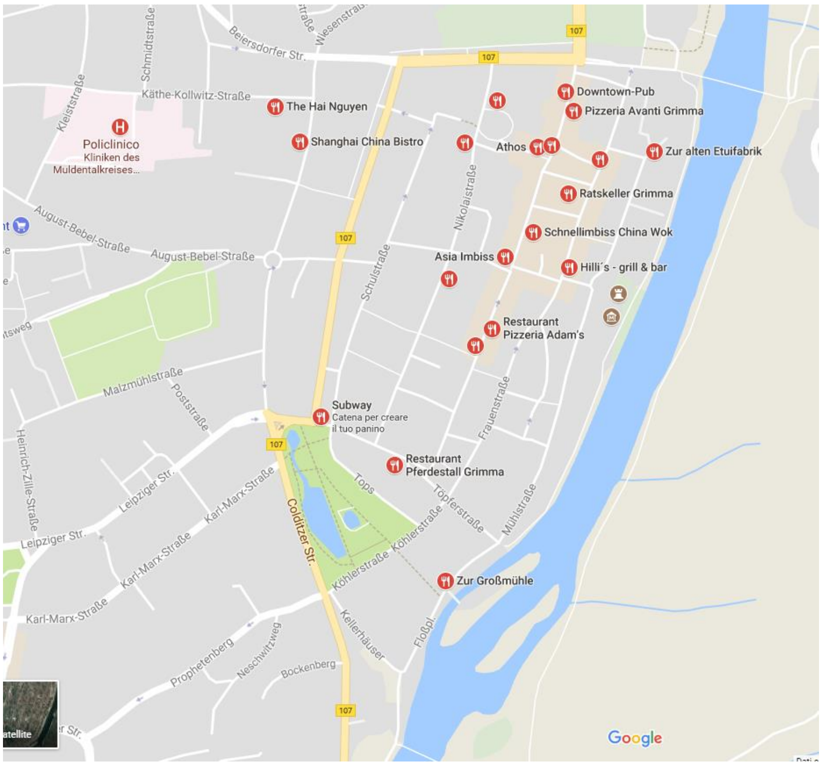


Figure 34 Restaurants and bars in Grimma centre 2017 (source: Googlemaps, 2017).

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 35).

As mentioned above, the new police headquarters 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.

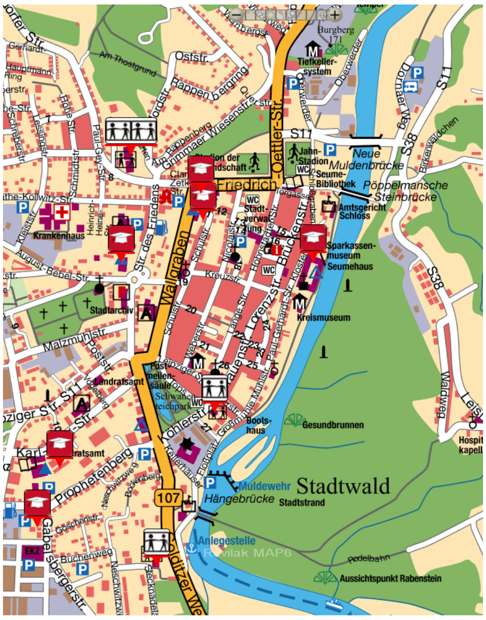


Figure 35 Schools and kindergartens in Grimma (source: Grimma municipality, http://grimma.bemap.eu/)

5.3.2 Prospective and corrective risk reduction and preparedness

5.3.2.1 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 kinds 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.).

5.3.2.2 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 2002 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 integrate 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 access 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 36):

- 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.

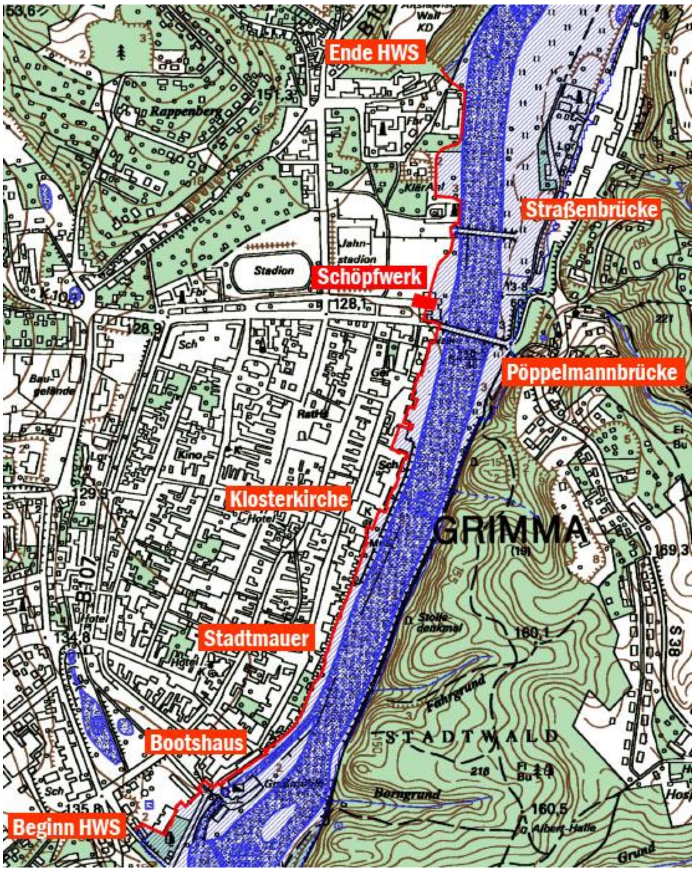


Figure 36 Flood wall projects for the town of Grimma (source: hochwasserschutz-grimma.de).

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 37) 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 38).

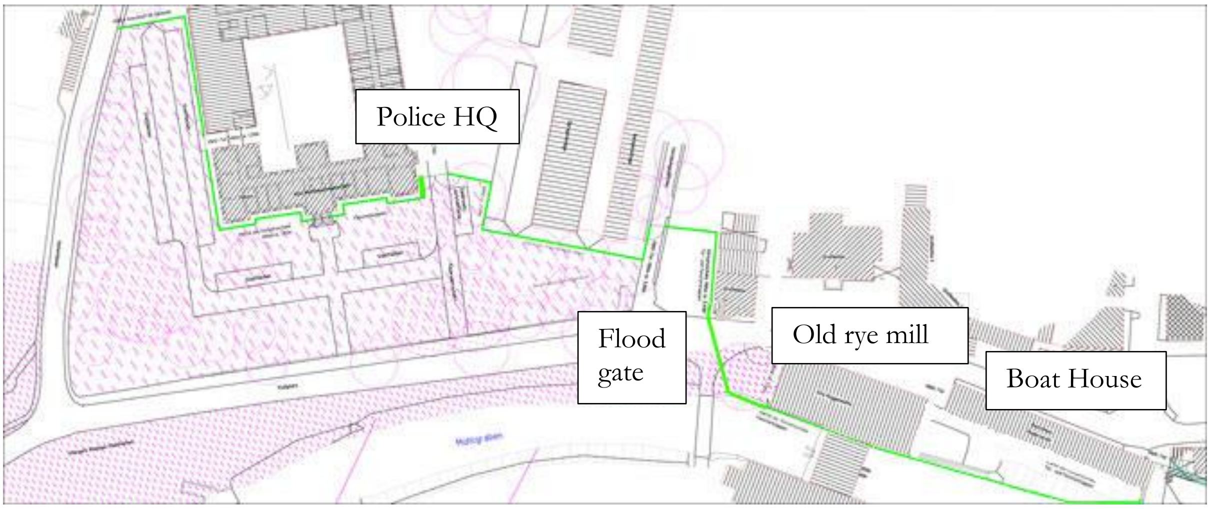


Figure 37 Project 1, floodwall (source: hochwasserschutz-grimma.de).

Figure 38 Floodgate, part of the floodwall Project 1 (source: author).

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 39). All three passages are equipped with a high-water protection gate on the waterside so that the waterways can be closed at short notice in case of imminent floods (hochwasserschutz-grimma.de, 2017).

Figure 39 New floodwall, part of Project 2, with passageways for accessing the river and allowing a view (source: author).

Figure 40 Floodwall, Project 2, under construction in June 2017 (source: author).

Project 3 covers the area between Klosterkirche (Monastery church) and the Pöppelmann bridge (Figure 41). In this case, the layout takes into account the buildings.

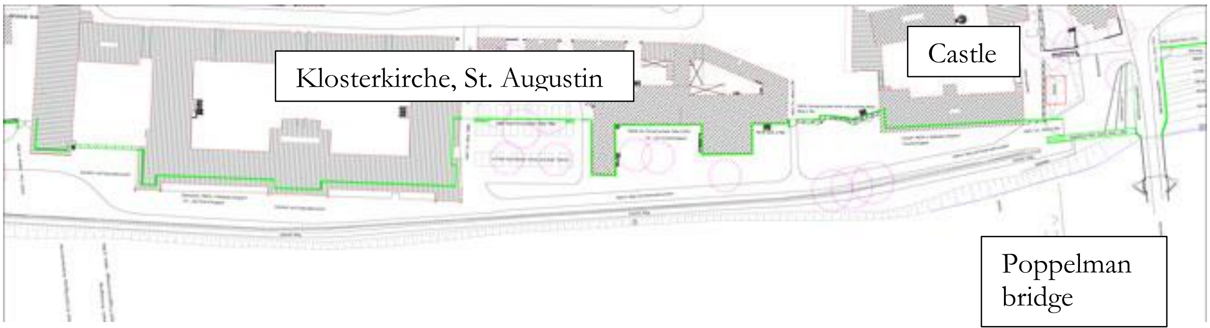


Figure 41 Project 3 layout (source: hochwasserschutz-grimma.de)

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 42).

Figure 42 Floodwall, project 4, under construction in June 2017 (source: author).

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 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 on the planned 40 Million (Spiegel, 2013).

5.3.2.3 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).

5.3.2.4 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 43 shows the percentage of households that took at least one precautionary measures before the 2002 flood and the 2013 flood events, respectively.

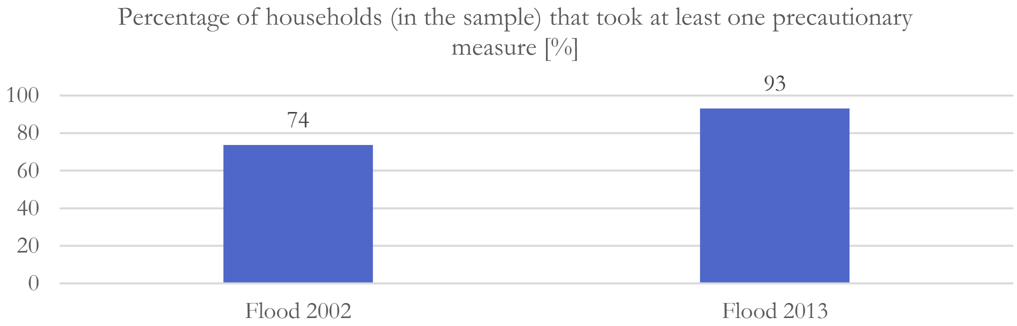


Figure 43 Percentage of households that took precautionary measures before the 2002 and 2013 flood events (source: author).

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 31 and Table 32).

Table 31 Precautionary measures classification for the 2002 flood event (source: author).

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 32 Precautionary measures classification for the 2013 flood event (source: author).

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 33). 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 33 Percentage of households that took at least one precautionary measure during the flood events (source: author).

	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.

5.4 SECTION III: WHAT HAPPENED?

5.4.1 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 44 New floodwall, photo taken across the Mulde River (source: author).

5.4.2 Disaster damages and impacts

The total losses for Grimma municipality 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 (Schiedlag, 2010).

A total of 750 buildings in the 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 Hangerbrucke was heavily damaged (Grimma Museum, 2002) due to debris. According to CNN (2002), the top of the Hangerbrucke 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 children consumption (ibid.).

Besides the damages and negative impacts, there were also some positive ones. 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 45).

Figure 45 New police station flooded during the 2013 flood (source: Colditzer-tageblatt, 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 (DW, 2013).

Figure 46 Suspension bridge covered in debris on June 6th, 2013 (source: 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).

5.4.2.1 Damage to the residential sector: 2002 and 2013 floods

Damages to de residential sector from the 2002 and 2013 floods are compared in this section as a means of researching their causal processes, as suggested in FORIN (Oliver-Smith et al., 2016). Figure 47 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.

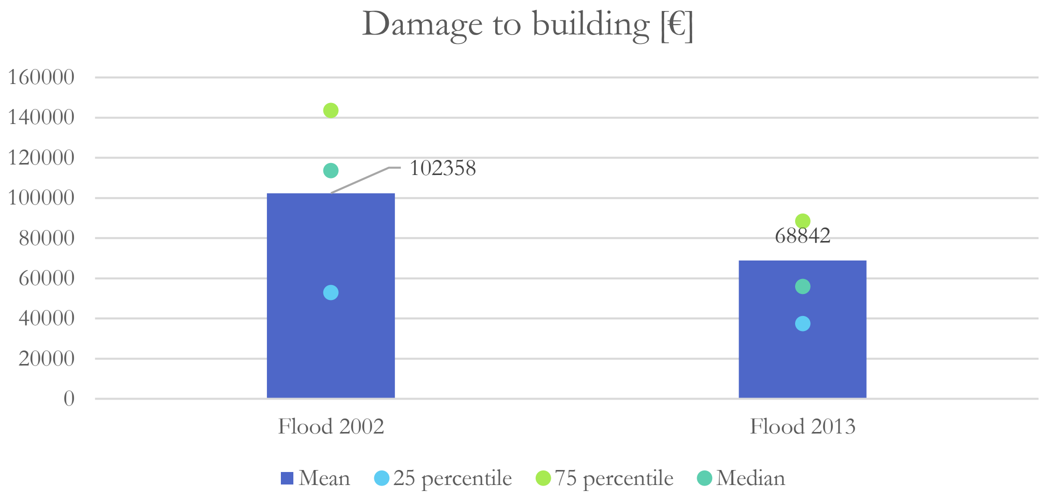


Figure 47 Damage to buildings (corrected for inflation to 2013) within the samples for the 2002 and 2013 floods (source: author).

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 48). The fact that damage to contents is very similar in both events could be explained by the important difference in flood duration.

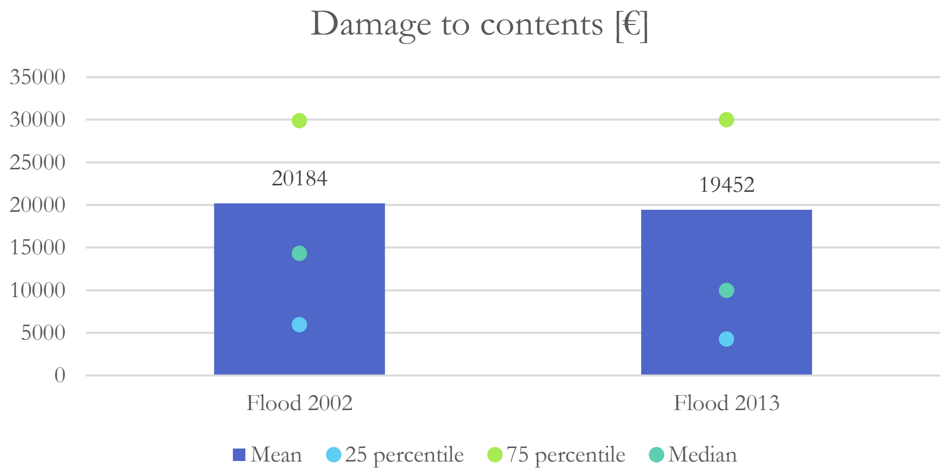


Figure 48 Damage to household contents (corrected for inflation to 2013) within the samples in 2002 and 2013 floods (source: author).

In order to rule out other factors that could have determined similar damage to contents during the 2013 flood event with respect to 2002, different hypotheses were generated and analysed, following the phases of the accident investigation. These hypotheses were generated by the author based on the knowledge of 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 have been flooded, and their contents damaged, which would add to the total damage to contents, even with lower water depth.

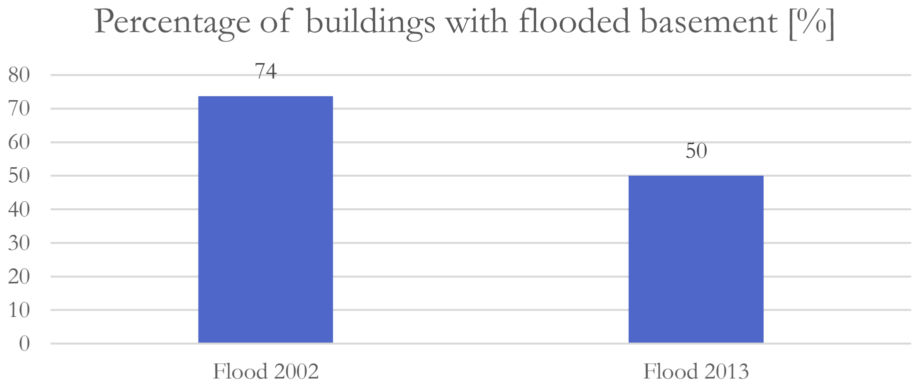


Figure 49 Percentage of buildings within the sample with flooded basements in the 2002 and 2013 floods (source: author).

Figure 49 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 34).

Table 34 Number of emergency measures taken for reducing damage to contents for 2002 and 2013 floods (source: author).

	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 35).

Table 35 Damage items categories for the 2002 and 2013 questionnaires (source: author).

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 36). Values for the number of reported items by household are slightly higher for the 2002 flood event.

Table 36 Number of damaged items (contents) reported by household for the 2002 and 2013 floods (source: author).

	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 (corrected to same year values) 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 50). This could have influenced the number of damages reported. However, without the 2002 data, it is difficult to conclude.

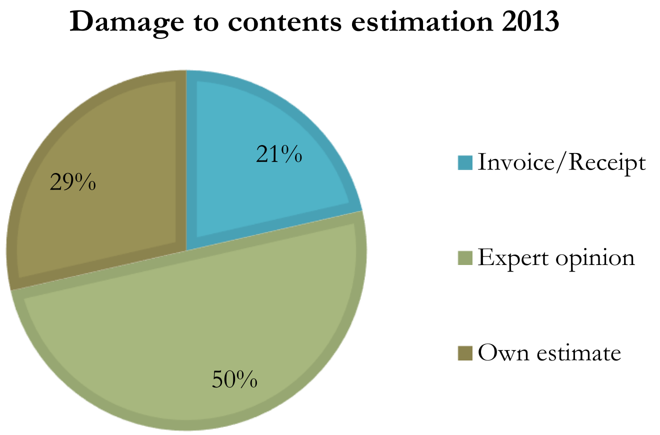


Figure 50 Damage to contents estimation for the 2013 flood event (source: author).

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.

5.4.2.2 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 51 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.

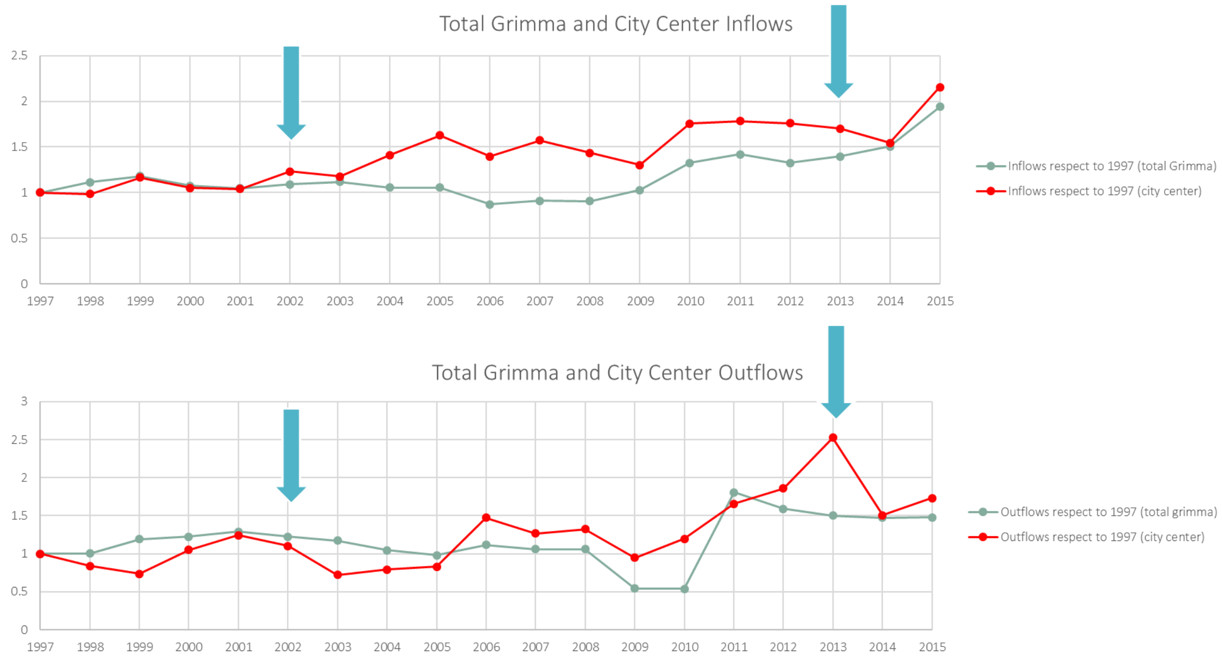


Figure 51 Total Grimma and city centre population inflows and outflows (source: author, based on data: years 1997-2008, Daniela Siedschlag (2010) and years 2008-2015 from Grimma municipal records).

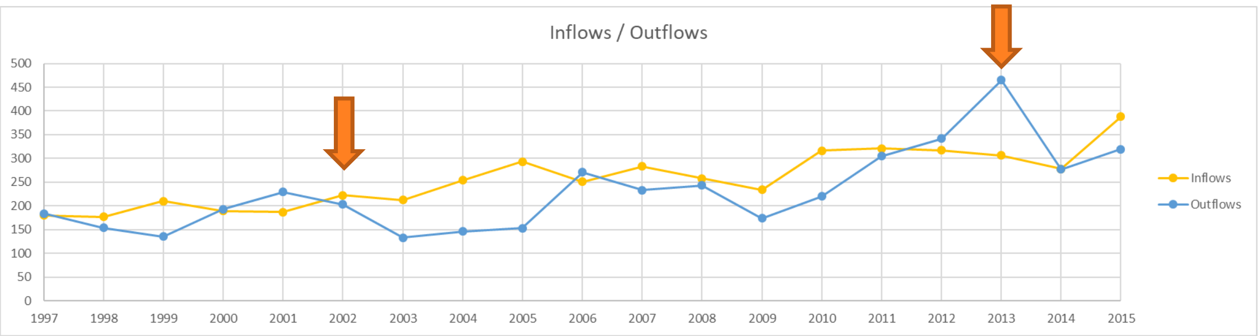


Figure 52 Grimma city centre population inflows and outflows (source: author, based on data: years 1997-2008, Daniela Siedschlag (2010) and years 2008-2015 from Grimma municipal records).

The difference between inflows and outflows (Figure 53) 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.

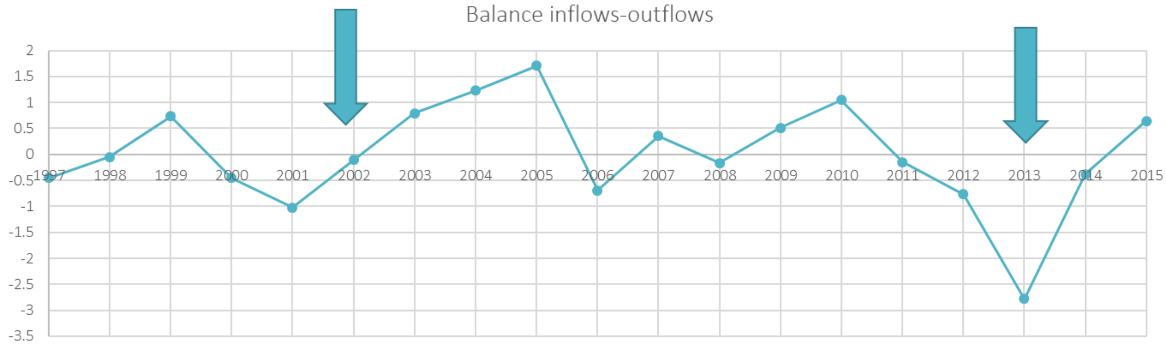


Figure 53 Normalized balance of population inflows-outflows in Grimma centre (source: author, based on data years 1997-2008, Daniela Siedschlag (2010) and years 2008-2015 from Grimma municipal data).

Age structure was also investigated, before and after the 2002 and 2013 floods. Results show that the age structure in the Grimma centre remained almost constant from 2001 to 2015 (Figure 54).

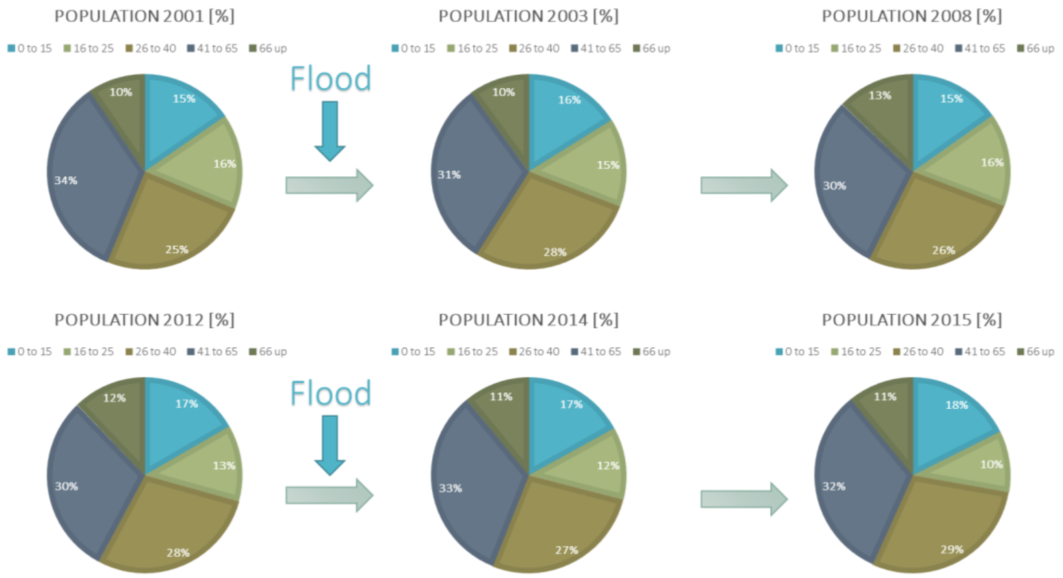


Figure 54 Age structure in Grimma inner-city in different years (source: author).

5.4.3 Emergency Response

In 2002, no timely flood warning was received in Grimma (Schanze et al., 2008). Data from the interviews at the household level 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 55). Other statistics such as the median and the mode also support this difference (Table 37).

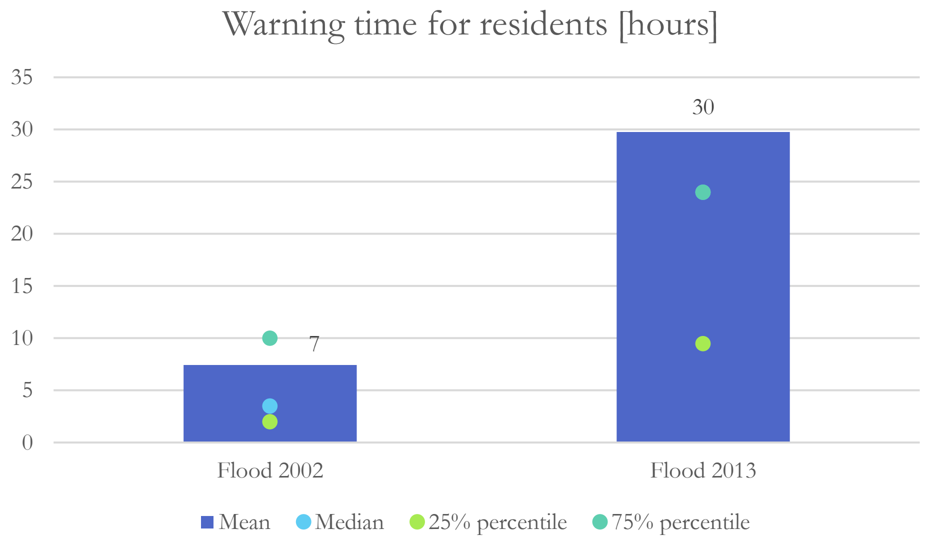


Figure 55 Warning time for residents within the samples [hours] (source: author).

The analysis of the data at the household level (Figure 56) 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 57) only 17% of the households in the sample did not receive any flood warning, while 78% received official warnings.

Table 37 Warning time statistics [hours] for the 2002 and 2013 flood event (source: author).

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

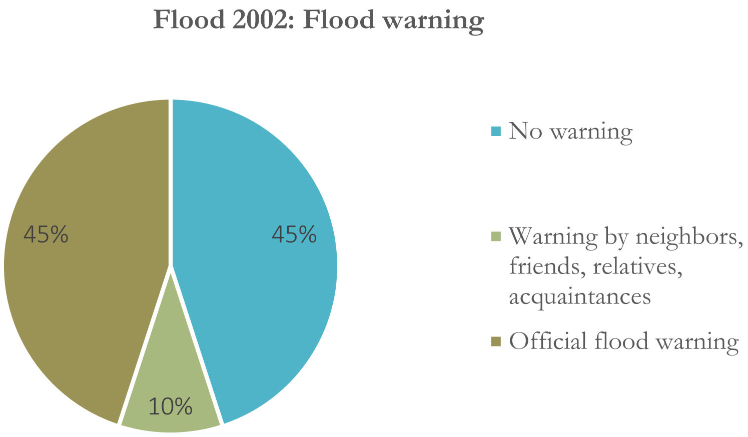


Figure 56 Flood warning distribution in households' data in the 2002 flood (source: author).

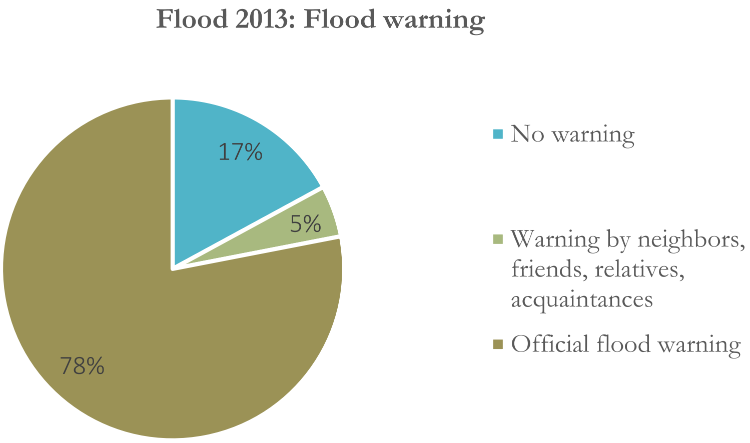


Figure 57 Flood warning distribution in households' data in the 2013 flood (source: author).

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 58, Figure 55 and Table 38).

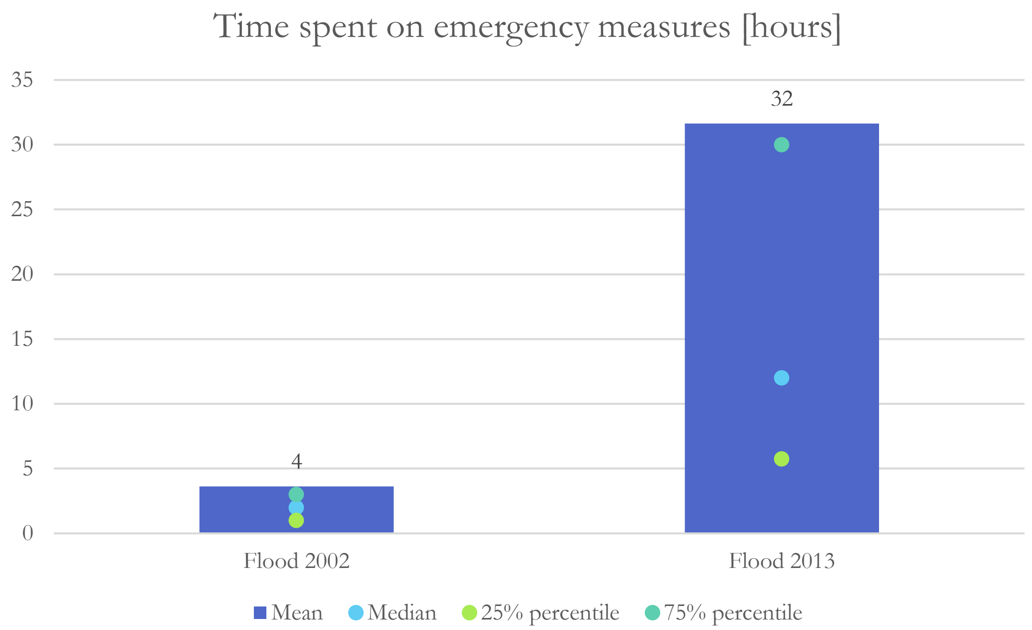


Figure 58 Time spent on emergency measures during the flood events [hours] (source: author).

Table 38 Time spent on emergency measures statistics [hours] during the flood events (source: author).

	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 59 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.

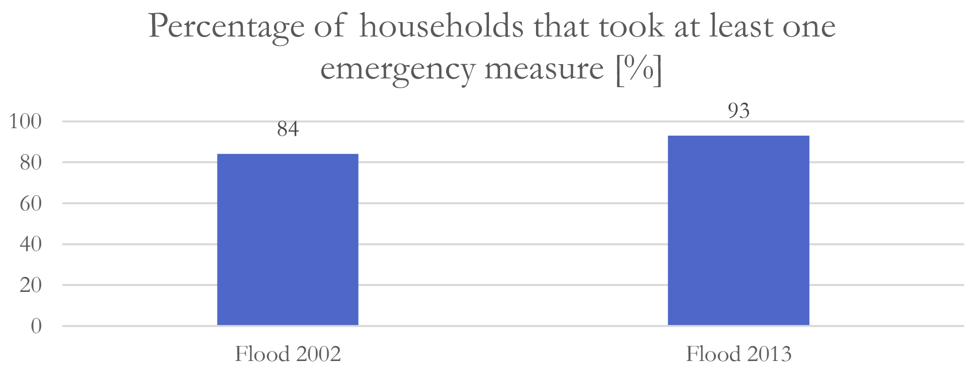


Figure 59 Percentage of households that took at least one emergency measures during the 2002 and 2013 flood events (source: author).

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 39 and Table 40).

Table 39 Emergency measures classification for the 2002 flood event (source: author).

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 40 Emergency measures classification for the 2013 flood event (source: author).

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 the entrance of water.

The percentage of households within the sample that took at least one emergency measure concerning each category was calculated (Table 41). 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. It is possible to see that in all cases the percentage of households that took at least one emergency measure is higher in 2013 with respect to 2002.

Table 41 Percentage of households that took at least one emergency measure during the flood events (source: author).

	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

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 12th, 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 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).

5.4.4 Recovery and Reconstruction

The 2002 flood attracted great media attention. As early as 14 August, 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, always 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 the 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 opened 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 60).

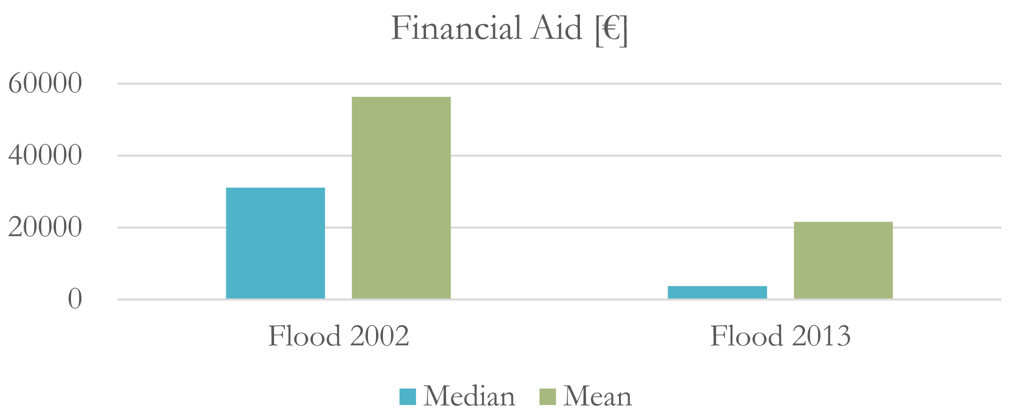


Figure 60 Financial Aid received by household after the 2002 and 2013 floods [€] (source: author).

This difference is also present when considering financial aid as a ratio to the total damage (Table 42). The ratio of the financial aid with respect to the total damage by household in 2002 is twice the one of 2013.

Table 42 Financial aid (corrected for inflation to 2013) for households in the sample of the 2002 and 2013 floods (source: author).

	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 if it 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. 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.

5.5 SECTION IV: LESSONS LEARNED

5.5.1 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, alongside firefighters. 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.

5.5.2 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 since 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.

5.5.3 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), 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 indicates that flood duration could be the most determining parameter in damages to contents in Grimma's floods.

5.5.4 Emergency 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 higher 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 city centre 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 worried 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.

5.5.5 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 suffered, 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., however, fieldwork showed that almost every building was renovated by 2017.

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.

5.5.6 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.).

6 CASE STUDY 2: UMBRIA REGION, ITALY

In this chapter, I develop the Umbria case study. Three localities are studied, i.e. Ponticelli in the municipality of Città della Pieve, and Orvieto Scalo and Ciconia in Orvieto municipality. These localities suffered an important flood in November 2012 with significant damages. These three localities are located inside the Tiber river basin. The new Disaster Forensic Investigation method, as developed in Chapter 4, is applied in the case study analysis, which is presented following the structure of the new method starting from a brief introduction.

6.1 INTRODUCTION

Between 11 and 14 November 2012, Umbria was hit by a flood event that caused significant damage and the request by the Region to declare a state of emergency to the National government (CFU, 2012). Both floods and landslides affected the regional territory, causing great damages to hydraulic works, agriculture, commercial and productive activities, infrastructure and private assets. Luckily, there were no deaths (CFU, 2012).

6.2 SECTION I: PHYSICAL CONTEXT

Precipitation on most of the regional territory reached exceptional values, which in a little more than two days amounted to one-third of the mean annual precipitation (CFU, 2012). The precipitation had a total duration of about 3 days: the most intense rainfall was observed between the morning of 11 November and the afternoon of 13 November 2012 (CFU, 2012).

6.2.1 Flood in Ponticelli area

Figure 61 shows the flooded areas in Ponticelli for the 2012 event, as reconstructed by Ballio et al. (2013). The map puts together the flooded areas reconstructed by CNR-Irpi (Barbetta et al., 2013) in blue, and the flooded areas reconstructed in yellow on the basis of the comparison between the topography of the affected area and the observations made by local authorities, the SOUR (the Regional Operational Room) and firefighters following the event. Reconstruction of the flooded area made by CNR-Irpi are based on photographic documentation of the event acquired on 12 November 2012. As stated by Ballio et al. (2013), the return period of the 2012 flood in the Paglia River is estimated between 100 and 200 years.

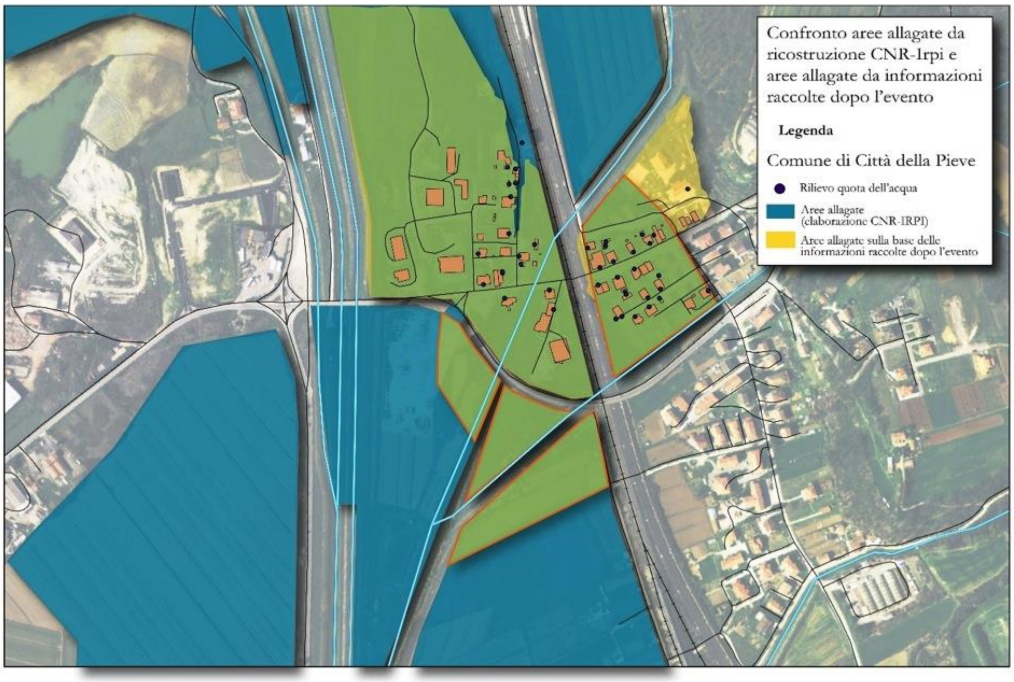


Figure 61 Flooded area in 2012 in Ponticelli (source: Ballio et al., 2013).

6.2.1.1 Comparison of 2012 flood and what was expected from hazard maps

The first available flood hazard map for the area of Ponticelli dates from July 2012 (4 months before the flood), from the First update of the PAI (Figure 62). The flooded area in 2012, as in Figure 61, is located inside bands A (50 years return period) and B (200 years), which is in line with the return period estimated for the 2012 flood (100-200 years). It is possible to conclude then that this was an "expected" flood, from the point of view of the available hazard maps of the time, and that the extension and return period of this flood are in line with the information on the hazard map.

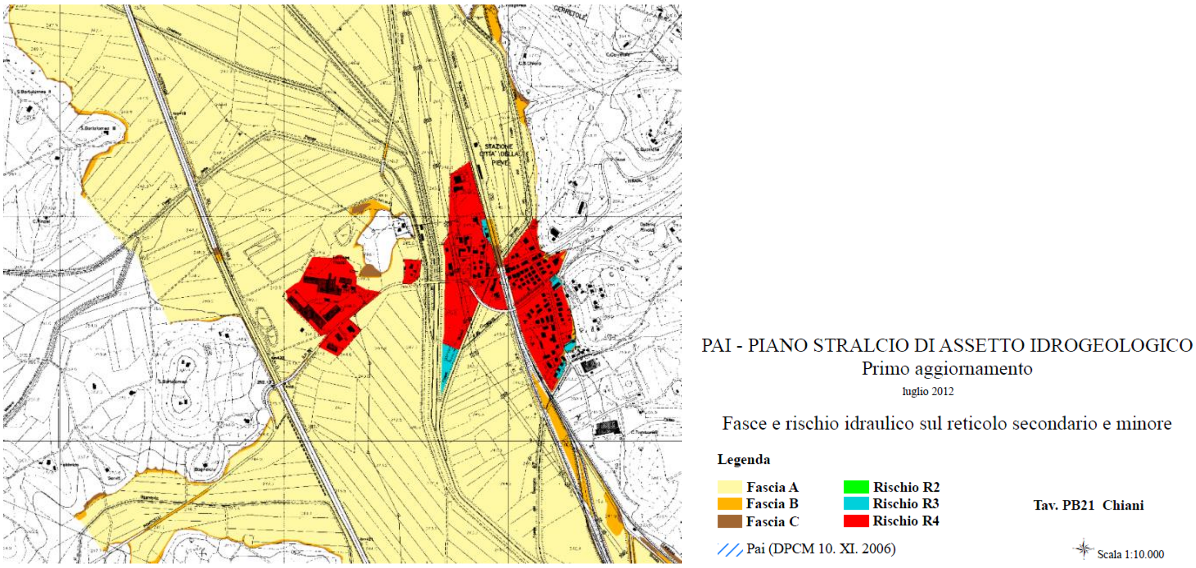


Figure 62 Flood hazard and risk map in the area of Ponticelli, Citta' della Pieve, from the P.A.I First Update (2012).

6.2.2 Flood in Orvieto Scalo and Ciconia areas

The discharge of the Paglia River reached values on November 12th, 2012, estimated at around 2300 m3/s in Orvieto Scalo hydrometric station, an event comparable only to the one of 1937, which calls for the thorough verification of the currently available statistical series (CFU, 2012).

The flood extension for the 2012 flood in Orvieto Scalo and Ciconia is shown in Figure 63, retrieved from the hydraulic study commissioned by Orvieto Municipality in 2013 (Ramazzina, 2013). The flooded area in the study is taken from the "Event Report" by the CFU (Centro Funzionale Regione Umbria). The hydraulic study (Ramazzina, 2013) confirms that the November 2012 event, characterized by rainfall of return period between 50 and 100 years, has caused flooding with an extension between the perimeters with return periods of 50 and 200 years.

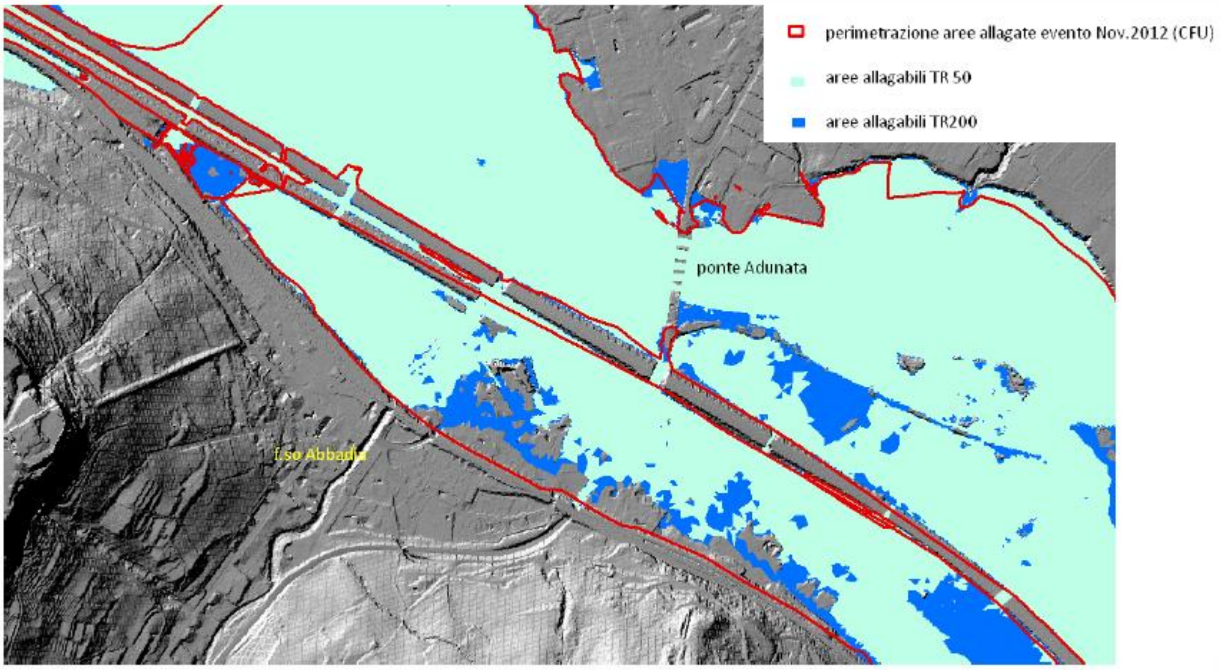


Figure 63 Flooded area in 2012 in Orvieto (source: Ramazzina, 2013).

Water depth in Orvieto Scalo near the Paglia river was around 2.30 m (Ballio et al., 2013). In the area of the Eni gas station (Figure 64), it was around 1 m (ibid.). It is important to note that the gas station is located in an area that is elevated with respect to the surroundings.

The data collected by the Polimi group of damaged industrial and commercial activities in Orvieto Scalo present mixed values regarding flood duration. Part of the sample reports that water remained in their buildings around 27 hours, whereas the other claims that water remained for 8 hours. In most of the cases, the owners and employees of the affected activities were blocked in the other side of the Adunata bridge, that was closed before the flood early morning on the 12th and could not access their property until the bridge was reopened in the afternoon. The eyewitness at the Eni gas station (Figure 64) reports that water remained for 28 hours.

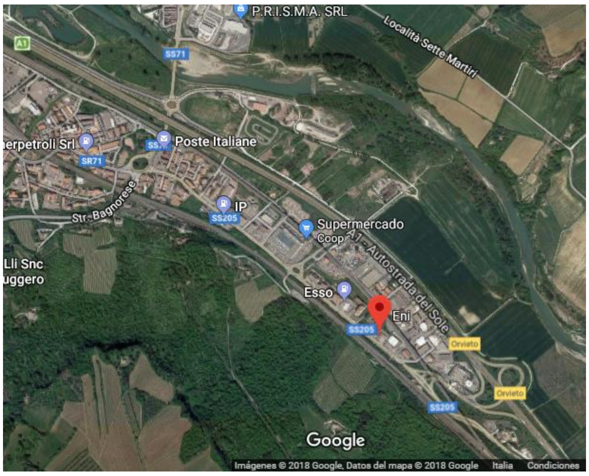


Figure 64 Location of Eni gas station, flooded in 2012 (source: Googlemaps, 2018).

In addition, the data collected by the Polimi group shows the presence of paint and fuel in floodwaters in Orvieto Scalo. The presence of these substances is coherent with the fact that a paint shop and a gas station are amongst the flooded commercial activities.

6.2.2.1 Comparison of 2012 flood and what was expected from hazard maps

The flood hazard map in force during the 2012 flood corresponds to the one from the first PAI ("Piano Stralcio Assetto Idrogeologico", basin plan), shown in Figure 65. The hazard map shows that the flood-prone area is mostly limited by the highway to the West and confined to the riverbed at the East, excepting two small areas, leaving most of Orvieto Scalo outside the flood-prone area. Clearly, the flood extension of 2012 does not coincide with the hazard maps in force in the basin plan in that date, where flooding was not expected in the majority of Orvieto Scalo.

Figure 65 First flood hazard and risk map of the Paglia and Chiani Rivers at Ciconia and Orvieto Scalo areas (source: P.A.I. First Update, 2008).

6.3 SECTION II.A: SPATIAL PLANNING ROLE IN SHAPING DISASTER RISK

6.3.1 Basin Plan Analysis: Tiber Basin

The Basin Plan Analysis examines the evolution of Basin Plans. The promulgation in Italy of Law 183/89 introduced for the first time planning at the basin level as a way to ensure land conservation and protection, water quality, rational use and management of water resources and related environmental protection. This law gave rise to the first basin plans projects, as in the case of the Tiber catchment, in 1999. These plans could be subdivided into sub-basins plans or coherent pieces ("stralci"). In particular, the "Piano Stralcio Assetto Idrogeologico" (P.A.I) was introduced with this law and in the Basin Plan Project, as the main instrument to identify and manage areas at hydraulic and geological hazard.

6.3.1.1 Tiber Basin Plan Project (1999)

The Basin Plan introduces the distinction between (i) program measures, related to the execution of construction works, (ii) norms that regulate human action and administrative functions in the territory and (iii) knowledge measures, in which all the possible contents of the basin plan are contained. Program measures include "permanent non-preventive measures" (punctual measures that guarantee population's safety), "permanent preventive measures" (measures that contain or reduce hazard on wider areas and are, thus, a priority) and “temporary and emergency measures” (measures for extreme events, taken during the crisis).

The Plan introduced five types of norms:

1. Direct norms: Total prohibition to modify the territory, or modifiability of the territory subject to control by the competent administrations.
2. Framework norms: Directives that regulate activity, i.e. "compatibility rules" that must be implemented and adapted by each competent public subject on matters pertaining to land protection (Regions, provinces, municipalities, state administrations, etc.) and concerning various aspects (agricultural use, design and execution of hydraulic works, regulation of discharges in water bodies, minimum vital flows, etc.).
3. Specific norms: These are directed to very specific activities such as the extraction of soil from the riverbed.
4. Incentive measures: Measures related to the use of public funds towards activities of lower environmental impact and environmental restoration or to the relocation of existing activities but also, for example, the identification of taxing policies able to favour the optimal use of resources.
5. Definition of administrative, management and procedural directives.

Last, knowledge measures have no normative character but are crucial for supporting the functions of the Basin Authority, as well as the activities of other administrative bodies. These measures are directed to the public with the aim of informing about resource availability and to promote behaviours that are in line with the protection of resources. Additional measures are addressed to other administrations, in order to acquire knowledge on the implementation of the Plan that facilitates the monitoring of its observance.

Regarding hydraulic hazard, the main objectives indicated by law 183/89 and that the Plan pursued are the following:

- The protection, conservation and regulation of watercourses.
- Flood moderation to reduce flood hazard.

In particular, the Basin Plan aimed at:

a) The protection and recovery of natural river dynamics consistent with the following points;

b) The protection of human settlements, infrastructures and assets of particular value as well as the protection of the population;

c) The protection of public goods from floods if this does not constitute an element of possible aggravation of the hydraulic conditions of the river.

These objectives are to be pursued through the “Piano Stralcio Assetto Idrogeologico” (P.A.I), the most appropriate instrument defined for this matter. The Basin Plan Project defined as well the required and desired elements to constitute a knowledge base (“quadro conoscitivo”) on flood hazard and risk:

- rainfall and river flow data;
- hydrological analysis;
- basic and detailed maps;

- mathematical models of flood propagation;
- data on human settlements and land use.

These data would permit to map the areas subjected to flood risk in the main watercourses of the catchment, as well as particularly risky situations in the secondary watercourses. The Basin Plan also delineated a first approach for the definition of three flood-prone areas or "bands" ("fascie P.A.I.") A, B and C, with different flood return periods or probability of flooding. These areas would then be confronted with land use to identify areas at risk.

6.3.1.2 P.A.I. (2006) and First Update P.A.I Project (2008) Tiber Basin

The P.A.I project for the Tiber basin was developed in 2002 and finally approved in 2006. The P.A.I pursues the improvement of the hydrogeological structure of the basin through structural interventions (preventive and for risk reduction) and normative for the correct management of the territory, the prevention of new risky situations, the application of risk reduction measures in cases of established risk.

Plan Description

The Plan was developed through the following activities:

- The identification of landslide hazard and risk areas.
- The identification of the hazard and hydraulic risk with reference to the main, secondary and minor watercourses, through the identification of the flood-prone areas for different return periods and the risk assessment of the elements exposed.
- The assessment of the hydrogeological efficiency of the basin.
- The analysis of trends in hydrogeological dynamics and territorial anthropization in order to identify the most critical situations and outline priorities for intervention.
- The definition of a complex set of structural and regulatory actions.

Regarding the definition of hydraulic risk, the hydrographic network has been subdivided into main, secondary and minor watercourses. In order to produce flood hazard maps, different flood-prone areas were identified (only for the main watercourses), as suggested by the Basin Plan Project, according to flood return periods. "Band A" ("fascia A") is considered the most hazardous due to the high probability of flooding, which corresponds to a return period of 50 years. "Band B" follows and has a return period of 200 years and "band C" a return period of 500 years. These hazard maps were combined with qualitative vulnerability/exposure maps (based mainly on land use) to produce flood risk maps. These exposure and vulnerability maps consider the value of the asset and its vulnerability and the possibility of loss of human lives in relation to the specific intended use of assets distributed in the area to classify areas in four degrees of "sensitivity": very high, high, average and low. Areas at risk were classified as follows:

- R4 (very high risk), for which the loss of human lives and serious injuries to people, serious damage to buildings, infrastructure and environmental heritage, the destruction of socio-economic activities is possible.
- R3 (high risk), for which people might be injured, damage to buildings and infrastructures with consequent non-functionality/usability, the interruption of the functionality of socio-economic activities and damage to the environment.
- R2 (medium risk), for which minor damages are possible to buildings, infrastructures and environmental assets that do not affect the safety of people, the viability of buildings and the functionality of economic activities.
- R1 (moderate risk), for which social, economic and environmental damage is marginal.

Norms

Norms defined in the P.A.I are immediately binding on the administrations and public bodies, as well as on private individuals. In "band A", the P.A.I. pursues the objective of ensuring general conditions of hydraulic safety, ensuring the free flow of the reference flood and the maintenance and/or recovery of the dynamic equilibrium of the riverbed and favouring the natural evolution of the river.

In band A, only the following are allowed (extracted from the P.A.I Technical Norms):

a) Demolition of buildings without reconstruction.

b) Interventions on buildings, on networks and infrastructures and on existing equipment, both private and public or of public utility, ordinary maintenance, restoration, building renovation, as well as works inside buildings, including the interventions necessary to adapt to seismic regulations, seismic prevention, the removal of architectural barriers and compliance with safety and hygiene work regulations, as well as the improvement of sanitary, functional, housing and production conditions. The above interventions may involve changes to the intended use without increasing the urban load, increase in volume but not the surface area, except for works necessary for the removal of architectural barriers and plant and technological adaptations in compliance with the regulations on safety and energy saving. Interventions that involve at least one of the following conditions:

   - Increase in volume;
   - Different distribution of existing volumes;
   - A different arrangement of the land base of buildings;
   - Change of intended use;
   - Modifications of the morphological characteristics of the areas;

   Must be carried out under conditions of hydraulic safety and without any change in the water flow. To this end, it is necessary to obtain the clearance from the competent hydraulic authority. These interventions cannot, however, entail volume below the level of the terrain.

c) Hydraulic protection interventions of areas and buildings exposed to risk, if these interventions do not jeopardize the hydraulic safety conditions upstream and downstream of the area in question.

d) Measures necessary to reduce the vulnerability of existing buildings, infrastructure and equipment and to improve the protection of the population without increasing surface area and volume.

e) Interventions for the expansion of public works or of public interest, referring to essential and non-relocatable services, as well as the creation of new linear and/or network infrastructures not otherwise localizable, including the creation of functionally connected items. It is also permitted to create outdoor sports and recreation equipment and facilities with the possibility of creating modest accessory artefacts. These interventions are permitted on the condition that they do not constitute a significant obstacle to the flow and/or significant reduction of the current flood retention capacity, do not constitute an impediment to the implementation of measures to mitigate risk conditions and are consistent with the planning of civil protection activities.

f) Interventions on networks and technological systems, refurbishment of facades and furnishing buildings, existing infrastructure and equipment, provided that they do not involve the creation of new volumes, under the conditions set out in letter e).

g) The construction of small-scale buildings to serve existing buildings, infrastructure, equipment and activities, carried out under conditions of hydraulic safety and without increasing the current level of risk.

h) Practices for correct agricultural activity with the exclusion of any intervention that involves modification of the morphology of the territory.

i) Interventions aimed at the sanitation of polluted sites, environmental recovery and in general the reconstitution of altered natural balances and the elimination of anthropogenic interference factors.

j) Temporary use, if they do not reduce the capacity of the riverbed, carried out in such a way as not to cause damage or be detrimental to public safety in the event of flooding.

k) Maintenance of hydraulic works.

l) Buildings aimed at the management of agricultural activities, provided they are carried out under conditions of hydraulic safety and without increasing the current level of risk.

m) Hydraulic defence interventions.

n) Mining activity.

o) Activities related to navigation provided they are included in sectoral or regional plans, and on the condition that they do not constitute a source of transport for the buoyancy of vehicles or materials during the flood.

p) Interventions related to the production of hydroelectric energy under conditions that do not change the reference flood regime.

It is necessary to obtain the permission of the competent authority on hydraulic matters for interventions referred to in letters c), j), k), l), m) and o).

In "band B", the P.A.I. pursues the goal of maintaining and improving the conditions of the area flooded by the reference flood, together with the conservation and improvement of the natural and environmental characteristics. In band B, only the following are allowed (extracted from the P.A.I Technical Norms):

a) All the interventions already allowed in band A, also with an increase in the volume and expansion and modification of uses.
b) Urban renewal works on infrastructure (network and punctual elements) and existing equipment, both private and public or of public utility, as well as the enlargement and modification of use.
c) Temporary deposits resulting from mining activity.
d) Interventions foreseen in general planning instruments in force at the date of entry in enforcement of the P.A.I., in homogeneous zones A, B and D (limited to the completion of residual lots in totally or partially urbanized areas), in zones F (limited to general and public facilities), subordinated to the implementation of safety measures.

Point d) refers to homogeneous zones A, B, D and F as defined by the Inter-ministerial Decree 1444/68, on the limits to building density, height, distance between buildings and maximum ratios between the spaces destined to residential and productive settlements and public spaces or for collective activities, public parks or parking area, to be respected in new planning instruments and the revision of existing ones. Homogeneous zones A refer to the parts of the territory affected by urban areas that are historical, artistic and of environmental value or by portions of them, including the surrounding areas, which can be considered an integral part of the agglomerations themselves. Zones B comprise parts of the territory wholly or partly built up (other than zones A). Zone D and F regard the parts of the territory destined to new settlements for industrial plants or similar facilities, and the ones destined for installations of general interest, respectively.

It is necessary to obtain the permission of the competent authority on hydraulic matters for interventions other than the ones referred to in letters c), j), k), l), m) and o) for band A. All interventions must be carried out under conditions of hydraulic safety and in such a way as not to constitute a significant obstacle to the water flow and/or significant reduction of the current capacity of reservoir, impediment to the implementation of mitigation and/or reduction of flood risk conditions and coherent with civil protection interventions.

In band C, the P.A.I. aims to increase the level of safety of the population through the implementation of prevention programs, as well as of emergency plans, taking into account risk assessments arising from the indications of the P.A.I. The forecasting and prevention programs and the emergency plans also concern the territories identified as Band A and Band B. The competent hydraulic authority shall express an opinion in the case of new constructions of linear infrastructures such as railways, highways and suburban roads.

Areas at very high risk (R4) are under the same limitations as the ones corresponding to band A. For zones at high risk (R3), limitations are valid according to the band in which they are included.

Given that the P.A.I was drafted in 2002 and approved in 2006, by that time new areas emerged under hydrogeological risk, due to both an advancement in hazard assessment and on the evolution of existing risky situations. Therefore, a first update of the plan was drafted in 2008.

Flood Hazard and Risk Maps Analysis

Both hazard and risk are included in the same map, resulting in an undercoverage of the area (only high and very high-risk areas are indicated). The first hazard and risk map of the Chiani and Paglia rivers (Figure 65) shows that only a small portion of Orvieto Scalo is considered as flood prone, in "band B", and at high risk (R3). This high-risk area was defined as such due to the presence of a police station and contiguous buildings, both classified with very high sensitivity. According to the flood risk map, the urbanised area in Ciconia is mostly out of the flood-prone area, excepting two areas at very high risk (R4) in correspondence to the stadium and a small residential area, both located in the most hazardous band (A). As previously stated, only the main watercourses were analysed for the development of the hazard and risk maps. Therefore, flood hazard from secondary and minor courses was not mapped, which includes the whole area of Ponticelli, in Citta' della Pieve, and partially the area of Ciconia, in Orvieto.

6.3.1.3 P.A.I. Tiber First Update (2012)

The 2006 P.A.I. foresaw that the Italian Regions developed hydraulic studies on the secondary watercourses. Therefore, the First Update of the P.A.I. of the Tiber, adopted in 2012, was developed to include these new results. In particular, flood hazard and risk maps were added for the Chiani River and its tributaries.

Flood Hazard and Risk Maps Analysis

The 2012 update of the P.A.I. presented for the first time hazard and risk maps for the area of Ponticelli, Citta' della Pieve (Figure 62). According to this map, the whole area of Ponticelli is located inside the band A ("fascia A"), and existing buildings are all situated in an area of very high risk (R4). This very high-risk area results from the combination of a very high probability of flooding (band A), and a very high vulnerability and exposure of assets, which include continuous residential buildings (presence of population) and industrial and commercial buildings.

The flood hazard and risk map of the Paglia and Chiani Rivers in the area of Orvieto Scalo and Ciconia was updated in 2013 due to the availability of new knowledge on flood hazard in the area (Figure 66). These modifications were most probably related to the occurrence of the 2012 flood, which revealed that the flood-prone areas as indicated by the "bands" fell short to represent the actual flooded areas. Main changes in the flood hazard map in the area of Ciconia include the following:

- The extension of band C at the right bank of the Chiani River;
- The exclusion of the stadium from the flood-prone areas;
- The definition of new hazardous areas (A, B and C) in correspondence to a minor watercourse, which affects residential areas;

- The extension of band C at the left bank of the Paglia River.

The stadium was excluded from the flood-prone area, and thus, from the very high-risk area. Instead, the residential area classified as very high risk in the 2008 map (Figure 65) continues as such in the updated version.

Changes in the flood hazard map in correspondence to Orvieto Scalo were even more drastic. Only a small portion of Orvieto Scalo was included in the first version of the hazard map. Instead, in 2013 all of Orvieto Scalo was included inside band B. In fact, all the area at the right bank of the Paglia River, until the railways, was included in bands A and B. At high-risk areas in Orvieto Scalo remained the same, in correspondence to the police station and the continuous and denser buildings.

Restrictions and norms defined in the 2006 P.A.I were maintained in the First Update. They were retained without modifications.

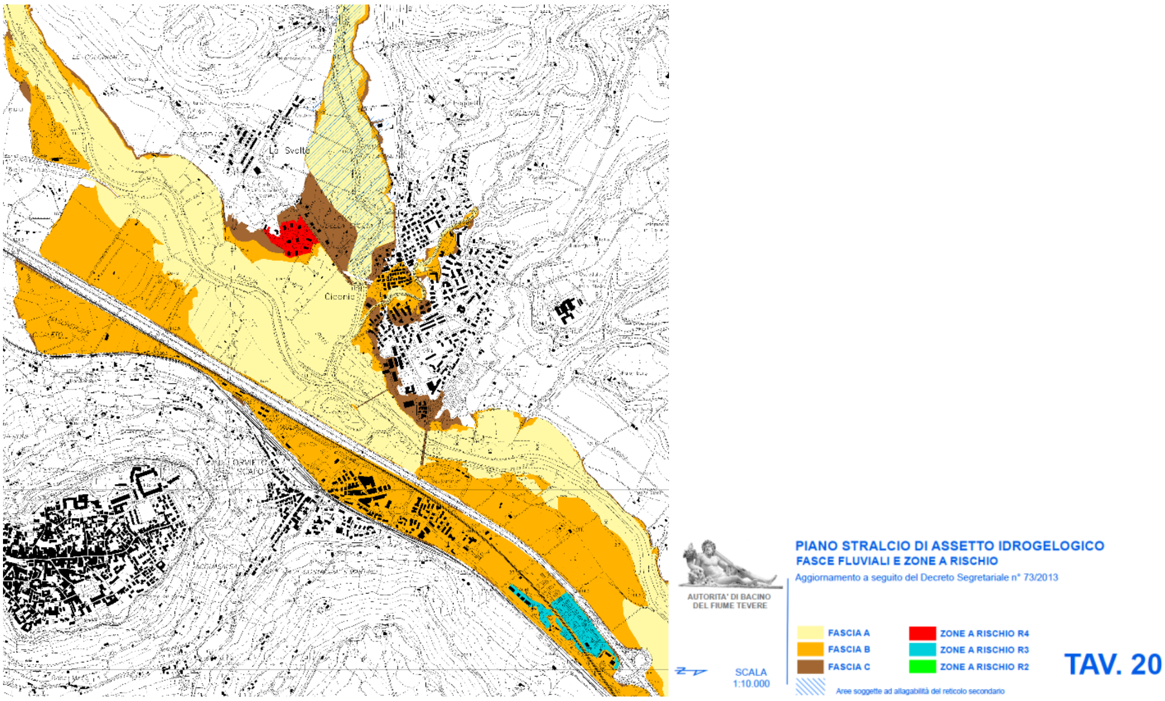


Figure 66 Update of flood hazard and risk map of the Paglia and Chiani Rivers at Ciconia and Orvieto Scalo areas (source: PAI, 2013).

6.3.1.4 Flood Risk Management Plan (F.R.M.P.) Tiber 2016

The 2007/60/EC Directive on the Assessment and Management of Flood Risks ("Floods Directive") was adopted on 18 September in 2007. In Italy, this European Directive was transposed in the Legislative Decree number 49 of February 23 of 2010. The purpose of the Floods Directive is to establish a framework for the assessment and management of flood risks in the European Community, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods. The Directive defines a six-year cycle, including the development of flood hazard and risk maps by 2013 on which to prepare Flood Risk Management Plans (F.R.M.Ps) by the end of 2015. Accordingly, flood hazard and risk maps must be reviewed and updated every 6 years (first revision end of 2019) and so must F.R.M.P.s (first revision end of 2021). These plans shall address all aspects of flood risk management focusing on prevention, protection and preparedness.

Plan Description

As a result of the Floods Directive and the associated Italian Legislative Decree, the Authority of the Tiber Basin prepared a new basin plan. Flood hazard maps were developed from existing maps from the P.A.I, including updates when available. P.A.I bands A, B, C were transformed in hazardous areas P1, P2, P3, respectively, considering floods with a high probability, floods with medium probability and floods with a low probability or extreme scenario.

Legislative Decree 49/2010 lists in more detail with respect to Directive 2007/60/EC the categories of exposed elements that must be considered in the flood risk maps, adding two further categories (infrastructure and cultural heritage) (Tiber Basin Authority, 2016). The following is a complete list of the categories of exposed elements reported in the decree (ibid.):

- Indicative number of potentially affected inhabitants;
- Strategic infrastructure and facilities (motorways, railways, hospitals, schools, etc.);
- Significant environmental, historical and cultural assets;
- Distribution and type of economic activities;
- Industrial plants (referred to in Annex I of Legislative Decree 59/2005), which could cause accidental pollution in the event of flooding;
- Protected areas (identified in Annex 9 of the third part of Legislative Decree 152/2006);
- Other information considered useful by basin authorities, such as areas subjected to floods with high volumes of solid transport and debris flows or information on relevant sources of pollution.

These exposed elements were classified in six macro-categories and identified through land-use maps: Urbanised areas, strategic facilities, strategic infrastructure, environmental assets and cultural heritage, economic activities and zones with productive or technological plants potentially dangerous from the environmental point of view. As opposed to what was done in the P.A.I., the vulnerability of exposed elements was defined as equal to one. This means that all the elements were considered equally vulnerable. Land-use data were complemented by census data on population to estimate the number of people at risk.

The Tiber F.R.M.P. includes both potential damage maps and risk maps. Maps of potential damages are classified into four qualitative categories:

- D4 (Very high potential damage): areas where loss of human life may occur, massive damage to economic, historical and cultural assets of major interest, serious ecological-environmental damages;
- D3 (High potential damage): areas with problems for people's safety and for the functionality of the economic system, areas crossed by lines of communication and services of considerable interest, areas where important productive activities are held;

- D2 (Average potential damage): areas with limited effects on people and socio-economic structure. Areas crossed by secondary infrastructures and minor productive activities, mainly destined for agricultural activities or to public green areas;
- D1 (Moderate or no potential damage): includes areas free of urban settlements or productive activities, where free water flow is possible.

These maps of potential damage are combined with the hazard maps (with the probability of flooding), to give rise to the flood risk maps. Four categories of risk were defined:

- R4 (very high risk): for which loss of life and serious injuries to people, serious damage to buildings, infrastructures and environmental assets, the destruction of socio-economic activities are possible.
- R3 (high risk): for which there are possible problems for people's safety, functional damage to buildings and infrastructures, the interruption of the functionality of the socio-economic activities and damage related to the environment;
- R2 (medium risk): for which minor damage to buildings is possible, to infrastructure and environmental assets that do not compromise people's safety, the integrity of buildings and the functionality of economic activities;
- R1 (moderate or no risk): for which damages to the population, economic activities and the environment are negligible or not present.

The F.R.M.P. states that the norms defined by the P.A.I (First Update) are still valid, particularly with respect to restrictions in territorial transformations.

Flood Hazard and Risk Maps Analysis

The flood hazard map remained the same both in the area of Orvieto Scalo/Ciconia and Ponticelli, only a reclassification was made from the bands A, B, C into P1, P2 and P3. Flood risk maps now cover the whole area and are not included anymore in the same map with the hazard, as it used to be in the P.A.I.

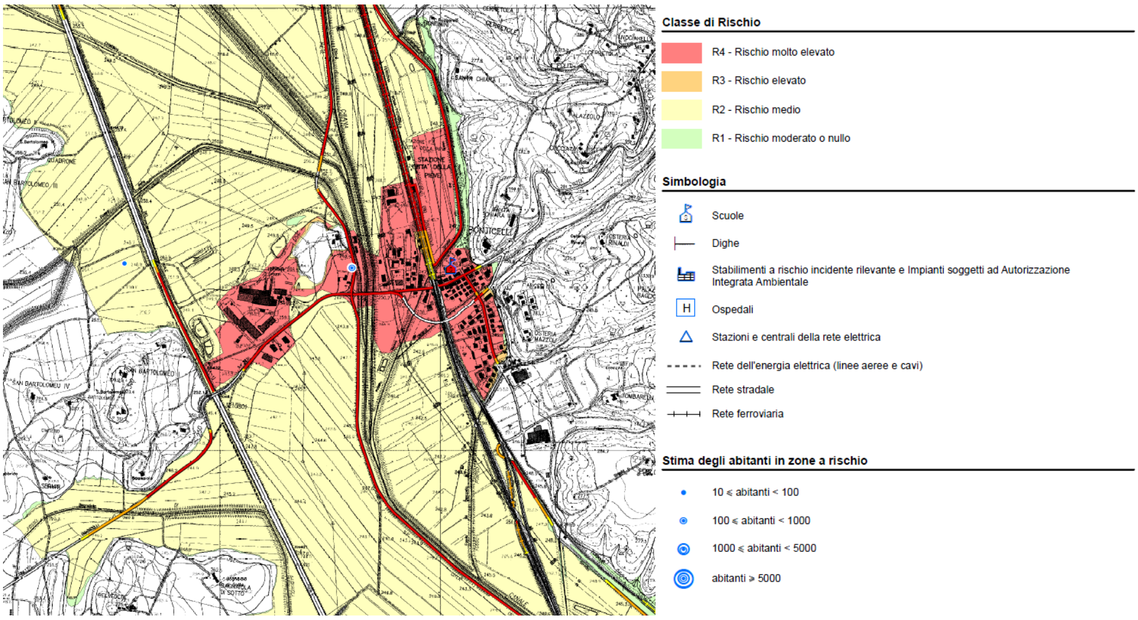


Figure 67 Flood risk map in the area of Ponticelli, F.R.M.P. Tiber (source: Authority Tiber basin, 2016).

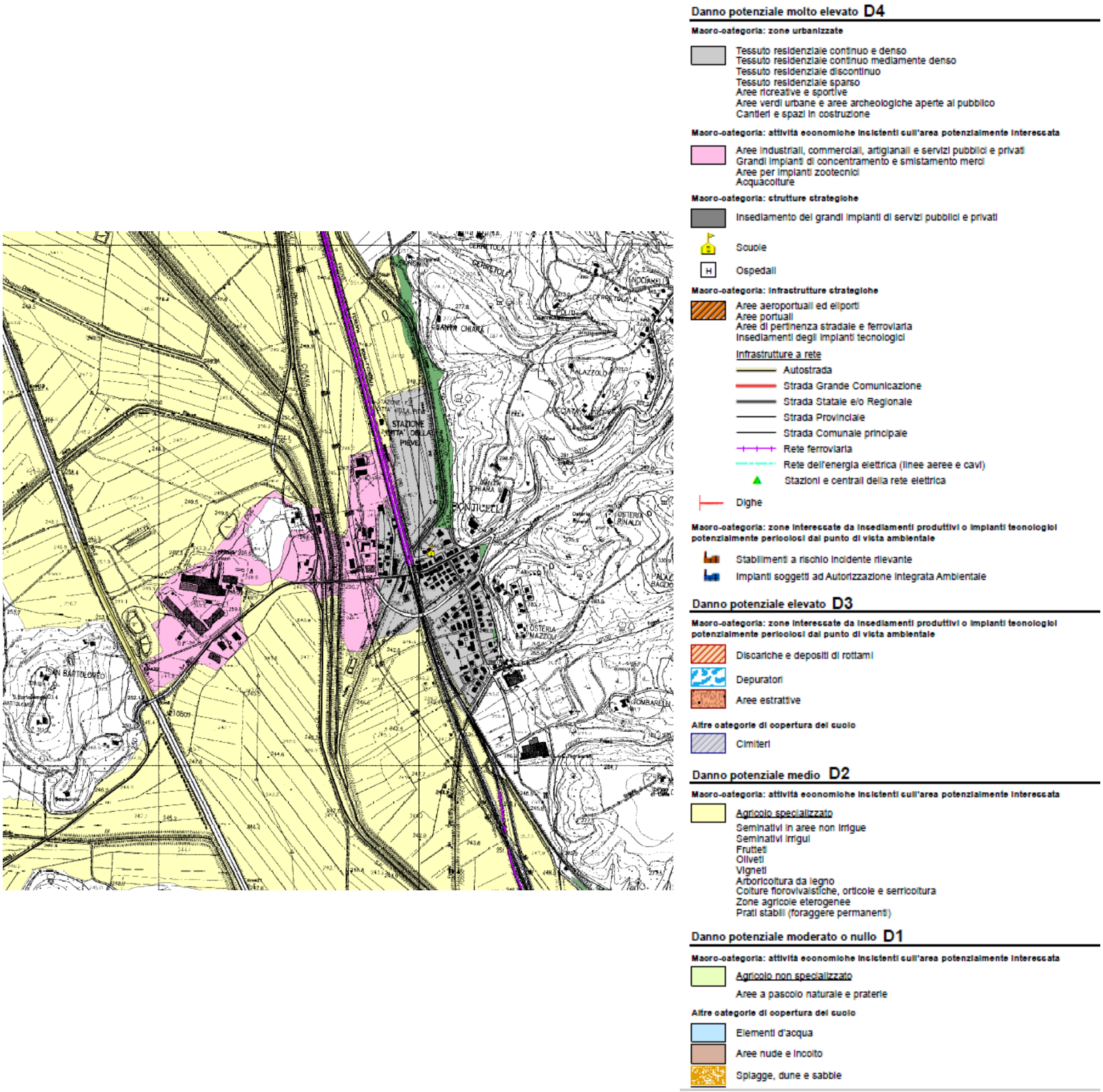


Figure 68 Potential flood damage map in the area of Ponticelli, F.R.M.P. Tiber (source: Authority Tiber basin, 2016).

The potential damage map in the area of Ponticelli (Figure 68) shows that the whole locality has a very high damage potential. It also shows that land-uses in Ponticelli are both residential and industrial/commercial. The flood risk map of Ponticelli (Figure 67) considers the complete built area as under very high risk, as in the P.A.I risk maps, but in this new version, the area was expanded to include an area near the train station and a bigger commercial/industrial area. The map also shows a school under very high risk, as well as a population between 100 and 1000 inhabitants. Infrastructure such as railways and provincial roads are also at very high risk.

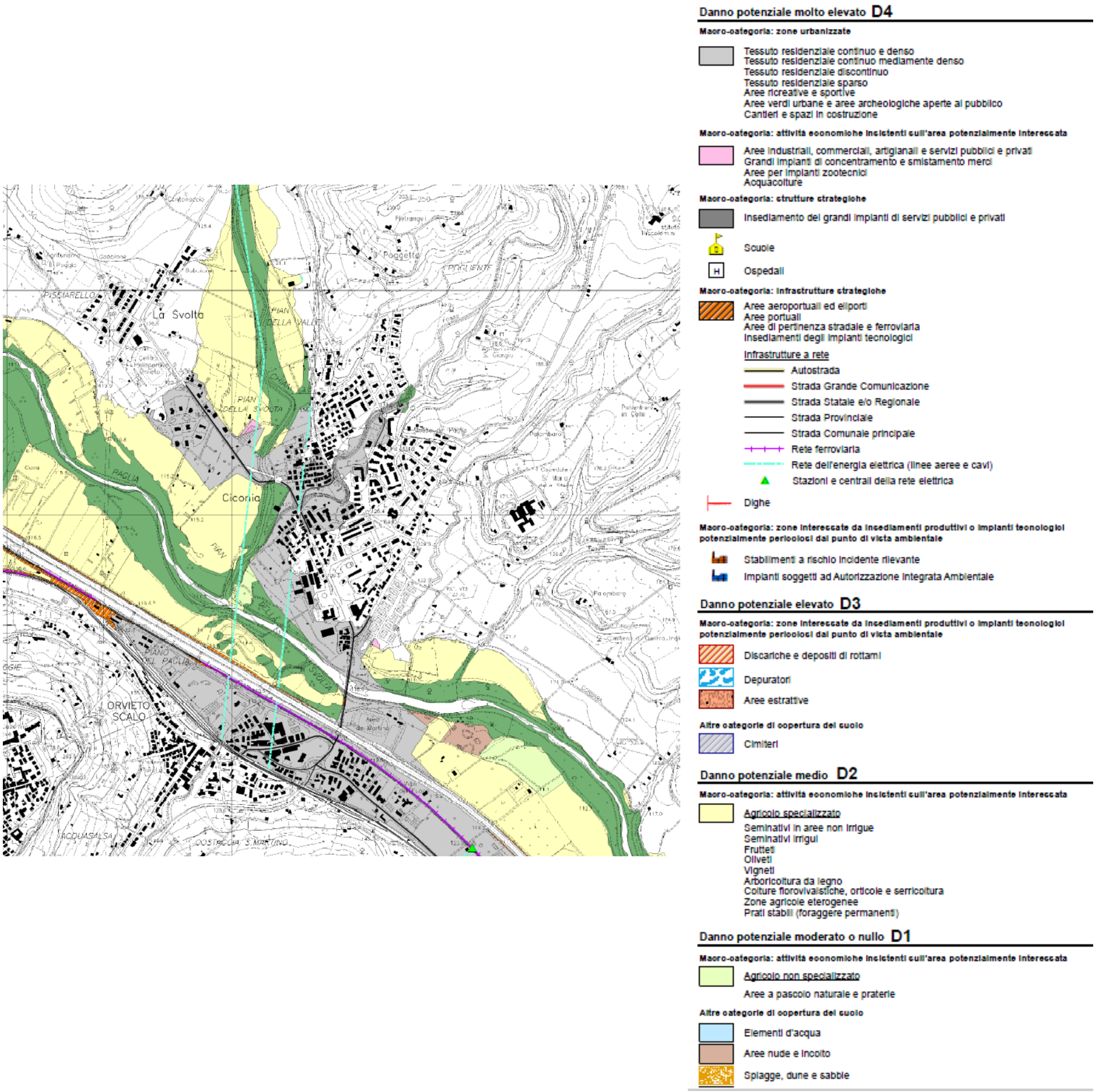


Figure 69 Potential flood damage map in the area of Orvieto Scalo/Ciconia, F.R.M.P. Tiber (source: Authority Tiber basin, 2016).

The potential damage map in the area of Orvieto Scalo (Figure 69) shows the whole area of Orvieto Scalo with very high potential damage, and classified as a residential area, even if some parts are mostly commercial/industrial. Urbanised flood-prone areas in Ciconia are classified the same way. The map also indicates two electric power lines with very high potential damage, as are the railways, provincial roads and the Adunata bridge.

The flood risk map at Orvieto Scalo (Figure 70) shows the whole built area under high risk, including the railways, roads and electric power lines that cross the Paglia River. Instead, Ciconia has some residential areas under very high risk, as well as under high risk, while most of the zone near the Paglia bank is at medium and low risk. The area that was previously classified as very high risk is now partially reclassified at medium risk.

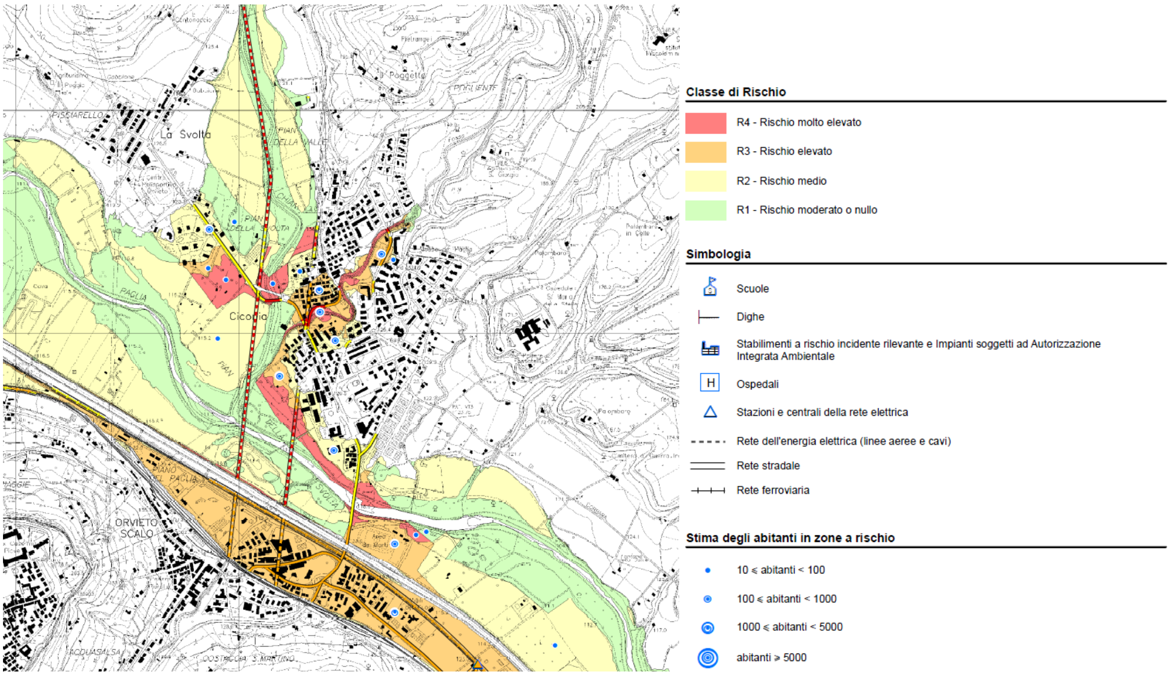


Figure 70 Flood risk map in the area of Orvieto Scalo/Ciconia, F.R.M.P. Tiber (source: Authority Tiber basin, 2016).

6.3.1.5 Conclusions of Basin Plan Analysis

The results of the analysis and comparison of the plans are summarised in Table 43, organised by basin plan and with different questions regarding flood hazard and risk maps and constraints to development in flood-prone areas.

Table 43 Results of the basin plans analysis (source: author).

Basin Plans	**Year**	**Questions**	**Localities**					
			Ponticelli		**Orvieto Scalo**		**Ciconia**	
			Yes/ No	**Comments**	**Yes/No**	**Comments**	**Yes/ No**	**Comments**
P.A.I. 2006/ 2008	2006-2008	Are flood hazard maps present for the localities?	No	Secondary watercourses were not mapped.	Yes		Yes	A minor stream was not mapped.
		Are flood risk maps present for the localities?	No	Secondary watercourses were not mapped.	Yes		Yes	A minor stream was not mapped.
		Does the plan limit development in flood-prone areas?	Yes, restrictions defined in bands A, B and C.					
P.A.I. 2012/ 2013 (First Update)	2012-2013	Are flood hazard maps present for the localities?	Yes	All Ponticelli is located in band A.	Yes		Yes	The minor stream was mapped.
		Are flood risk maps present for the localities?	Yes	All buildings under very high risk.	Yes		Yes	
		Did flood hazard maps change from one plan to the other? How?	-		Yes	All Orvieto Scalo in band B.	Yes	Extension and new hazardous areas in all bands.
		Did flood risk maps change from one plan to the other? How?	-		No	The map only shows at high and very high-risk areas, which did not change.	Yes	The stadium was excluded from a very high-risk area.
		Did the norms addressing development change from one plan to the other? How?	No, they were maintained the same.					

Basin Plans	Year	Questions	Localities					
			Ponticelli		Orvieto Scalo		Ciconia	
			Yes/ No	**Comments**	**Yes/No**	**Comments**	**Yes/ No**	**Comments**
F.R.M.P. 2016	2016	Are flood hazard maps present for the localities?	Yes		Yes		Yes	
		Are flood risk maps present for the localities?	Yes		Yes		Yes	
		Did flood hazard maps change from one plan to the other? How?	No	Only reclassification of categories.	No	Only reclassification of categories.	No	Only re-classification of categories.
		Did flood risk maps change from one plan to the other? How?	Yes	All the area is mapped. Expansion of the area at very high risk.	Yes	All the area is mapped. Infrastructure was added. All the built area at high risk.	Yes	All the area is mapped. More densely built areas mostly at high and very high risk.
		Did the norms addressing development change from one plan to the other? How?	No, they were maintained the same.					

6.3.2 Ponticelli, Citta' della Pieve: Evolution of the built environment and local plan analyses

The method developed for investigating the role of spatial planning in shaping risk, as part of the disaster forensic investigation, is applied in the locality of Ponticelli, Citta' della Pieve, following the scheme in Figure 71. The *Analysis of the Evolution of the Built Environment* will be presented next. The *Local Urban Plan Analysis* in Ponticelli area will follow.

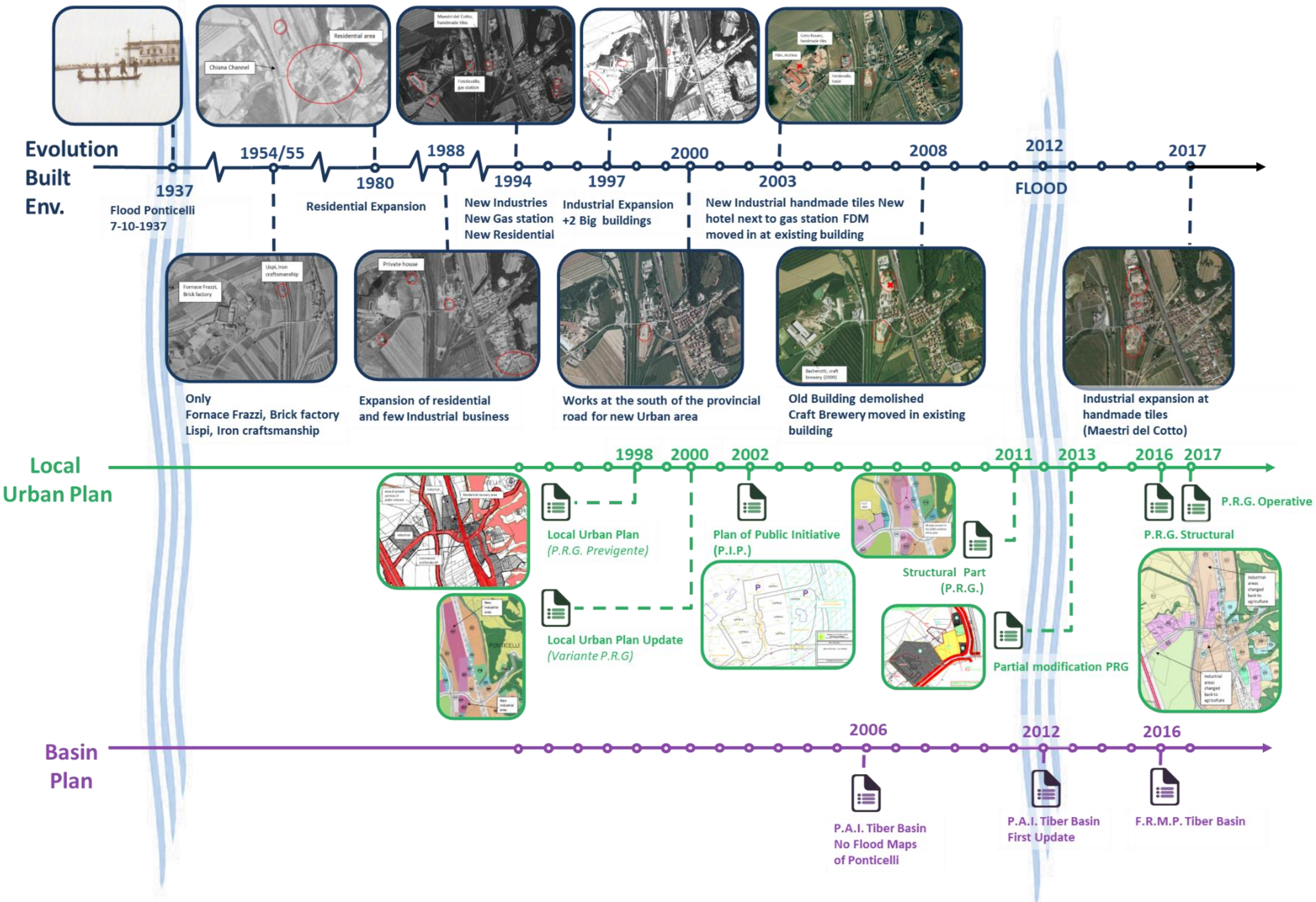


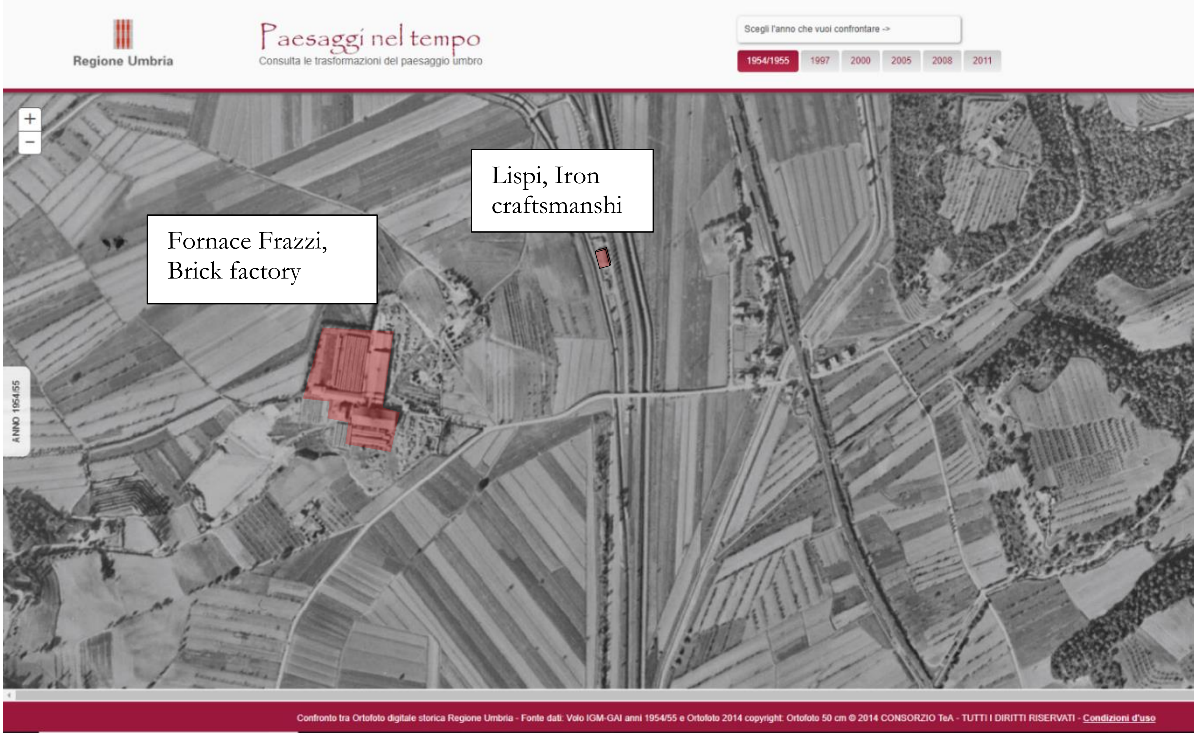
Figure 71 Ponticelli Case Study, Investigation of the role of Spatial Planning in shaping disaster risk (source: author).

6.3.2.1 Analysis of the Evolution of the Built Environment

This part of the investigation is focused on understanding changes in the built environment through the analysis of orthophotographs and satellite images.

Years 1954-1955

The first available orthophoto of the area dates from 1954-1955 (Figure 72), from the Umbria Region Environmental and Territorial Information System (Sistema Informativo Ambientale e Territoriale). It is possible to see in this orthophoto the presence of two handicraft industries, a very important brick factory (Fornace Frazzi) and an iron craftsmanship (Lispi), the second one still present today (2018). The Frazzi brick factory was a historic company, the most important in the Valdichiana area. In 1936, the brick factory was sold and went under refurbishment. The works were interrupted by the important flood of 1937, which breached the protection wall, and flooded the whole factory (Fornace della Memoria, 2018). During the reconstruction and repair, the existing building was refurbished and a second furnace and building were constructed. The brick drying area was established at the second level (ibid.). The Frazzi company suffered from an economic crisis and closed its business between 1969 and 1979.



Confronto tra Ortofoto digitale storica Regione Umbria - Fonte dati: Volo IGM-GAI anni 1954/55 e Ortofoto 2014 copyright: Ortofoto 50 cm © 2014 CONSORZIO TeA - TUTTI I DIRITTI RISERVATI - Condizioni d'uso

Figure 72 Orthophoto of Ponticelli in 1954/1955 (source: http://siat.regione.umbria.it/paesaggineltempo/)

Year 1980

The next available orthophoto dates from the year 1980, from the U.S. Geological Survey, the sole science agency for the Department of the Interior. Figure 73 shows a residential area at the right of the railways, a new provincial road as well as some small industries between the Chiana Channel and the railways.

Figure 73 Orthophoto of Ponticelli in 1980 (source: https://earthexplorer.usgs.gov/)

Year 1988

The following orthophoto dates from 1988, available at the national geo-portal of the Italian Ministry of Environment (Figure 74). The image shows an expansion of the residential area, as well as the construction of some new small industrial buildings.

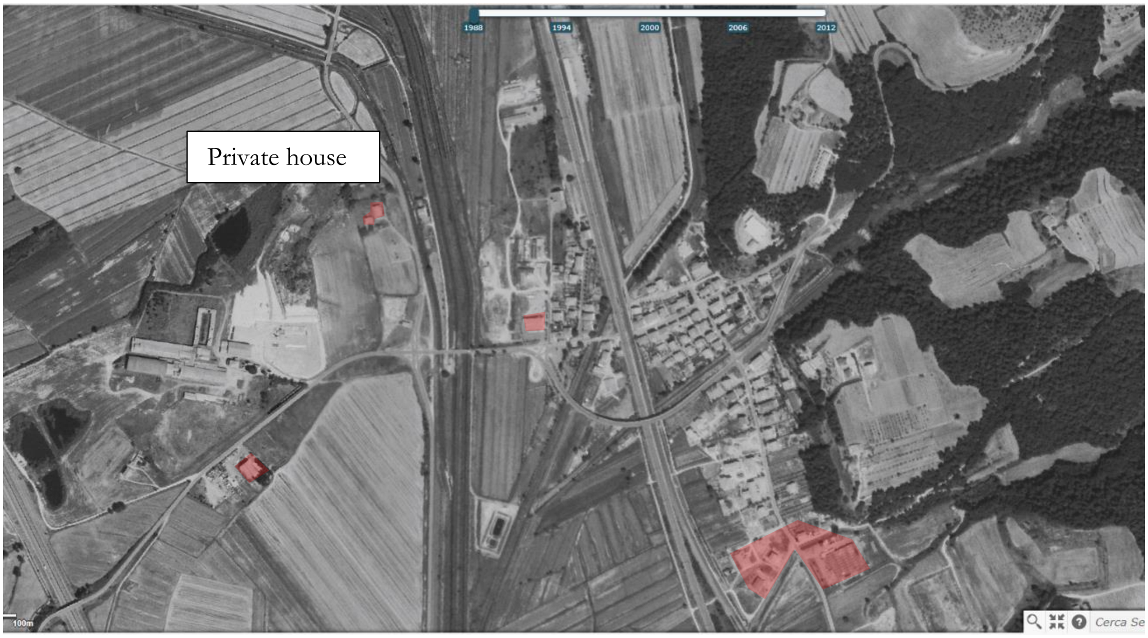


Figure 74 Orthophoto of Ponticelli in 1988 (source: http://www.pcn.minambiente.it/viewer/)

Year 1994

The 1994 Orthophoto (Figure 75) shows the presence of new industries, a gas station and some new residential buildings. Most of the new industrial buildings were located at the right bank of the water channels.

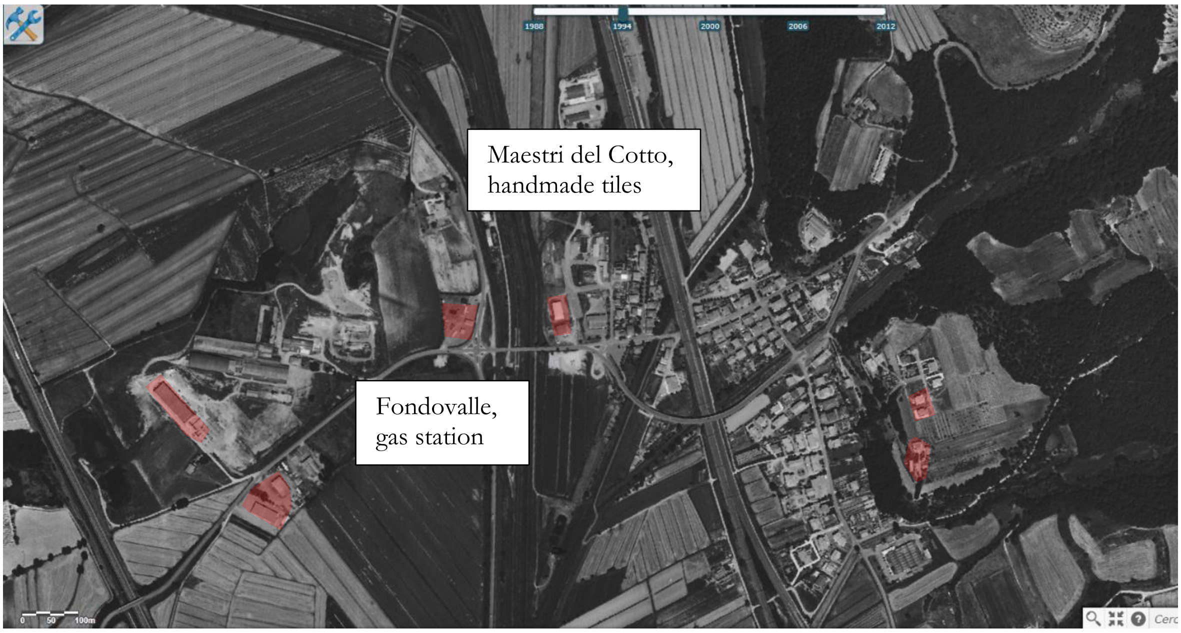


Figure 75 Orthophoto of Ponticelli in 1994 (source: http://www.pcn.minambiente.it/viewer/)

Year 1997

The 1997 orthophoto from the Regional Information System (Figure 75) shows some new industrial buildings that serve existing ones. In particular, two important buildings were added in the industrial area at the right bank of the water channels.

Figure 76 Orthophoto of Ponticelli in 1997 (source: http://siat.regione.umbria.it/paesaggineltempo/).

Year 2000

The orthophoto from the year 2000, from the Regional Information System, shows the beginning of construction works at the south of the provincial road. These correspond to the development of new urban infrastructure that would serve a future built area (Figure 77).

Figure 77 Orthophoto of Ponticelli in 2000 (source: http://siat.regione.umbria.it/paesaggineltempo/)

Year 2003

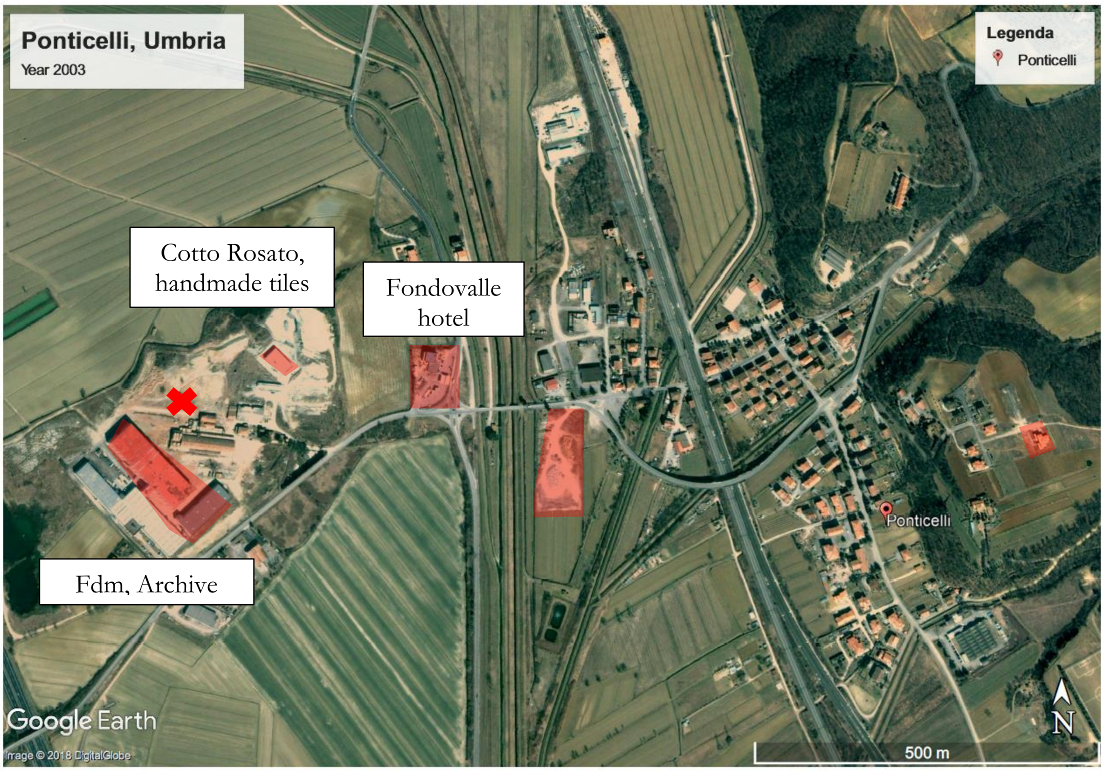


Figure 78 Ponticelli in 2003 (source: GoogleEarth Pro).

A satellite image of the year 2003 was retrieved from Google Earth Pro (Figure 78). It shows some changes in the built environment at the west of the water channels. These include the establishment of a new industry for handmade tiles and a hotel next to the gas station. Another important change was the settlement of Fdm, an Italian company for document management and archiving. Fdm demolished one of the existing buildings, which remained from the historic brick factory, and built a new one. Works on urban infrastructure continued south of the provincial road. Between 2003 and 2005, another old building from the old brick factory was demolished (Figure 79).

Years 2005-2008

Between 2005 and 2008, another old building was demolished, but this time in the industrial area next to the railways. Urban infrastructure works are still ongoing in the south of the provincial road (Figure 80). New activities were located in existing buildings, such as a craft brewery.

Confronto tra Ortofoto digitale "TerraItaly™ NR" ©Compagnia Generale Ripreseaeree S.p.A. – Parma anno 2005 e Ortofoto 2014 copyright: Ortofoto 50 cm © 2014 CONSORZIO TeA - TUTTI I DIRITTI RISERVATI - Condizioni d'uso

Figure 79 Orthophoto of Ponticelli in 2005 (source: http://siat.regione.umbria.it/paesaggineltempo/)

Confronto tra Ortofoto digitale AGEA anno 2008 e Ortofoto 2014 copyright: Ortofoto 50 cm © 2014 CONSORZIO TeA - TUTTI I DIRITTI RISERVATI - Condizioni d'uso

Figure 80 Orthophoto of Ponticelli in 2008 (source: http://siat.regione.umbria.it/paesaggineltempo/)

Year 2013

A satellite image from Google Earth Pro of 2013 (Figure 81) shows that the only modifications were made in the industrial area next to the railways. A new building was added, while works for the development of new urban infrastructure began.

Figure 81 Ponticelli in 2013 (source: GoogleEarth Pro).

Year 2017

A 2017 satellite image (Figure 82) shows that there was an expansion in one of the existing industries (Maestri del Cotto) that makes handmade tiles. The new urban infrastructure, both north and south from the provincial road, are still under development.

Figure 82 Ponticelli in 2017 (source: GoogleEarth Pro).

The results of the analysis of the evolution of the built environment for Ponticelli are synthesised in Table 44. It is possible to see that flood exposure has been growing since 1955 at a high rate. However, around the 2000s this growth stopped and then it slowed down up to date.

Table 44 Results of the Evolution of the Built Environment Analysis in Ponticelli (source: author).

Year	**Changes in Exposure**	**Changes in Exposure**	**Land use**
1954/ 1955	Few handicraft industries, brick factory, agriculture and railways.	Baseline	Industrial, handicraft, agriculture, railways.
1980	New industries, roads and important residential area.	(+)	Industrial, handicraft, residential, railways, roads.
1988	Expansion of residential area, new small industries.	(+)	Industrial, handicraft, residential, railways, roads.
1994	New industries, new residential buildings and a gas station.	(+)	Industrial, handicraft, services, residential, railways, roads.
1997	New industrial buildings.	(+)	Industrial, handicraft, services, residential, railways, roads.
2000	New local road and infrastructure for southern part of the provincial road, previously agricultural land.	(+)	Industrial, handicraft, services, residential, railways, roads.
2003	New handicraft industries and a hotel.	(+)	Industrial, handicraft, services, residential, railways, roads.
2005/ 2008	Almost no changes in the built environment.	(=)	Industrial, handicraft, services, residential, railways, roads.
2013	New internal road to access a plot in an industrial area next to the railways, new building in the industrial area.	(=+)	Industrial, handicraft, services, residential, railways, roads.
2017	Expansion of one industrial building.	(=+)	Industrial, handicraft, services, residential, railways, roads.

6.3.2.2 Local Urban Plan Analysis, Citta' della Pieve

The locality of Ponticelli is in the municipality of Citta' della Pieve. Citta' della Pieve's local urban plans (P.R.G., "Piano Regolatore Generale") were retrieved and analysed, with a focus on the land use maps in the area of Ponticelli. The results of the Local Urban Plan Analysis of the municipality of Citta' della Pieve are synthesised in Table 45. Each plan is explained in detail in the next paragraphs.

Table 45 Results of the Local Urban Plan Analysis of Citta' della Pieve (source: author).

Local Urban Plans Citta' della Pieve	**Year**	**Locality**	**Flood hazard/risk considered**		**Land use/future uses**	**Land use changes**
			Yes/ No	**How?**		
P.R.G. Previgente	1998	Ponticelli	No	Only the preservation of forests near the river, which is not respected.	Industrial areas, commercial/handicraft areas, residential "recovery" area, services.	-
Variante P.R.G.	2000	Ponticelli	No	-	New industrial areas, next to the railways, south of the provincial road and next to the service area.	Transformation from agriculture to industrial use.
Variante P.R.G. - Piano attuativo di Iniziativa Pubblica (P.I.P.)	2002	Ponticelli	No	-	Plotting for new industrial area, next to the existing service area.	Transformation from agriculture to industrial use.
P.R.G. Parte Strutturale	2011	Ponticelli			The area next to the service area now considered as productive use of recent formation. The other two industrial areas are still indicated as expansion zones. A new area is set for industrial use at the West.	Transformation from agriculture to industrial use.
Variante Parziale P.R.G.	2013	Ponticelli	No	It states that there are no constraints in terms of flood risk. Norms from the 2011 plan do not apply because this was approved with the 2002 P.I.P.	Modification of use of area next to services.	Transformation from industrial to commercial/small industries/handicraft

Local Urban Plans Citta' della Pieve	**Year**	**Locality**	**Flood hazard/risk considered**		**Land use/future uses**	**Land use changes**
			Yes/ No	**How?**		
P.R.G. Parte Strutturale	2016	Ponticelli	Yes	Flood hazard and risk map from the First Update of the P.A.I. (2012) included. The P.R.G. states that areas falling within flood-prone zones must follow the P.A.I. Technical Norms. These are not retroactive for approved plans.	Modification of use of industrial areas next to railways, South of provincial road and West.	Transformation from industrial to agriculture.
P.R.G. Parte Operativa	2017	Ponticelli	Yes	It states that P.A.I.'s Technical Norms prevail over the P.R.G.	Distinction between industrial areas for new development, completion and with operational instrument in place. Municipal lots on sale in new industrial development area.	-

Local Urban Plan 1998 (P.R.G. Previgente)

The *P.R.G. Previgente* was approved on May 22nd, 1998. It consists of three land use maps that cover the whole municipality and of the related technical norms. Special constraints are mentioned in the 1998 Plan technical norms, indicating that these prevail over the plan's indications, also in case of laws and regulations adopted after the plan's approval. Regarding hydrogeological risk, two norms are cited: R.D. 3267 of 30/12/1923 and related regulation n° 1126 of 16/05/1926. These regulations indicate a 150m band from the Chiani River (fosso), where forests have to be preserved (Figure 83). This area intersects part of the built area of Ponticelli.

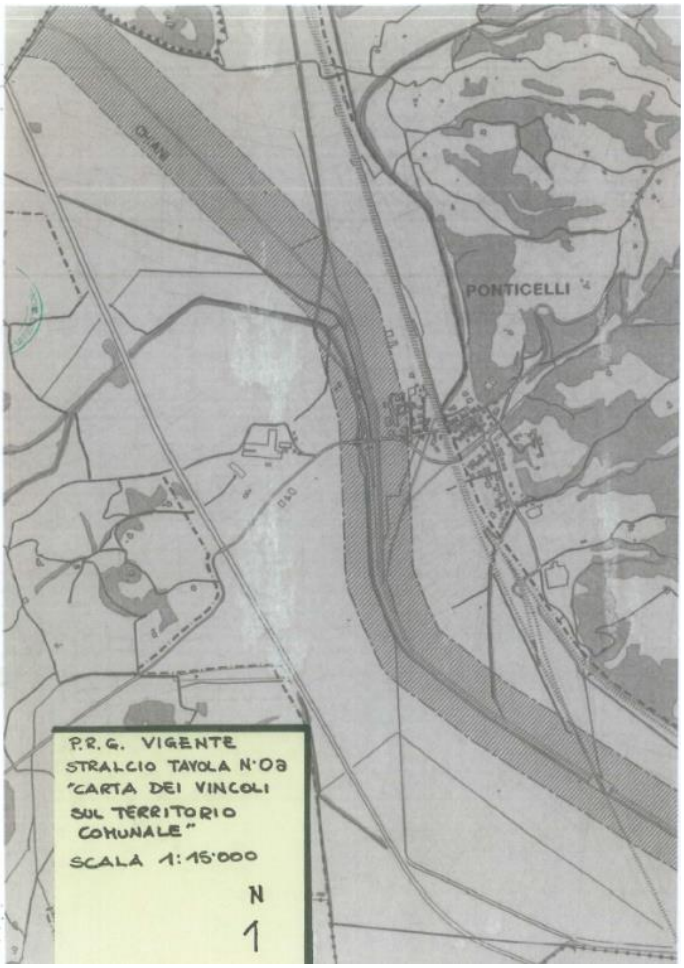


Figure 83 "Map of constraints in the municipal area" 1998 Urban Plan (source: Variante Parziale al P.R.G).

Moreover, the plan defines norms that derive from a geomorphological study, in particular, technical and construction norms for buildings in flood-prone areas. Unfortunately, these documents are not available.

Land-use Map Analysis in Ponticelli

Figure 84 shows the part of the land use map that corresponds to Ponticelli. On the left, it is possible to see two big industrial areas, as well as two commercial and handicraft areas. A "residential recovery" area was defined next to the commercial/handicraft. In these areas, it is possible to renovate buildings, including expanding them in surface, height and volume. Underground levels are allowed, to support both the residential and commercial activities. The aim is to "recover" or regenerate this residential area, by changing existing building typologies to more "coherent" and functional ones, constituting a "formally correct" urban tissue. The areas in white indicate agricultural areas.

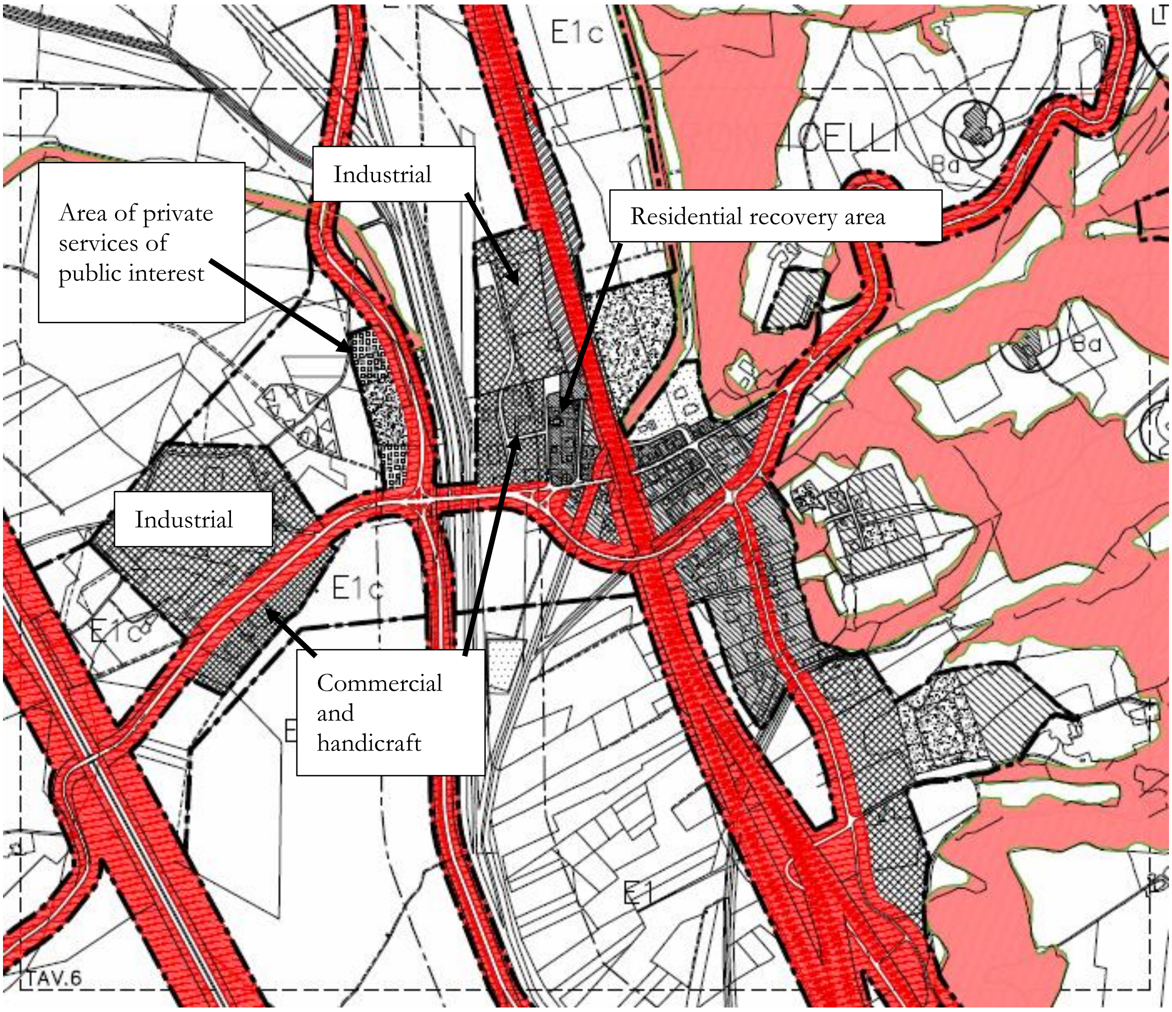


Figure 84 Local urban plan of Citta' della Pieve, P.R.G. previgente, 1998 (source: Comune di Citta' della Pieve).

Modification of Local Urban Plan 2000 (Variante P.R.G.)

Modifications of plans under enforcement are usually made. In this case, the most significant changes introduced by the 2000 modification plan are new industrial areas (former agricultural). These are analysed next.

Land-use Map Analysis in Ponticelli

The most important new industrial area indicated in the new version of the land-use map, is the one that is a continuation of the existing industrial zone parallel to the railway. As it is possible to see in Figure 85, this new area is more than twice the existing industrial area next to the railways. Moreover, south of the provincial road, a brand new industrial area was defined.

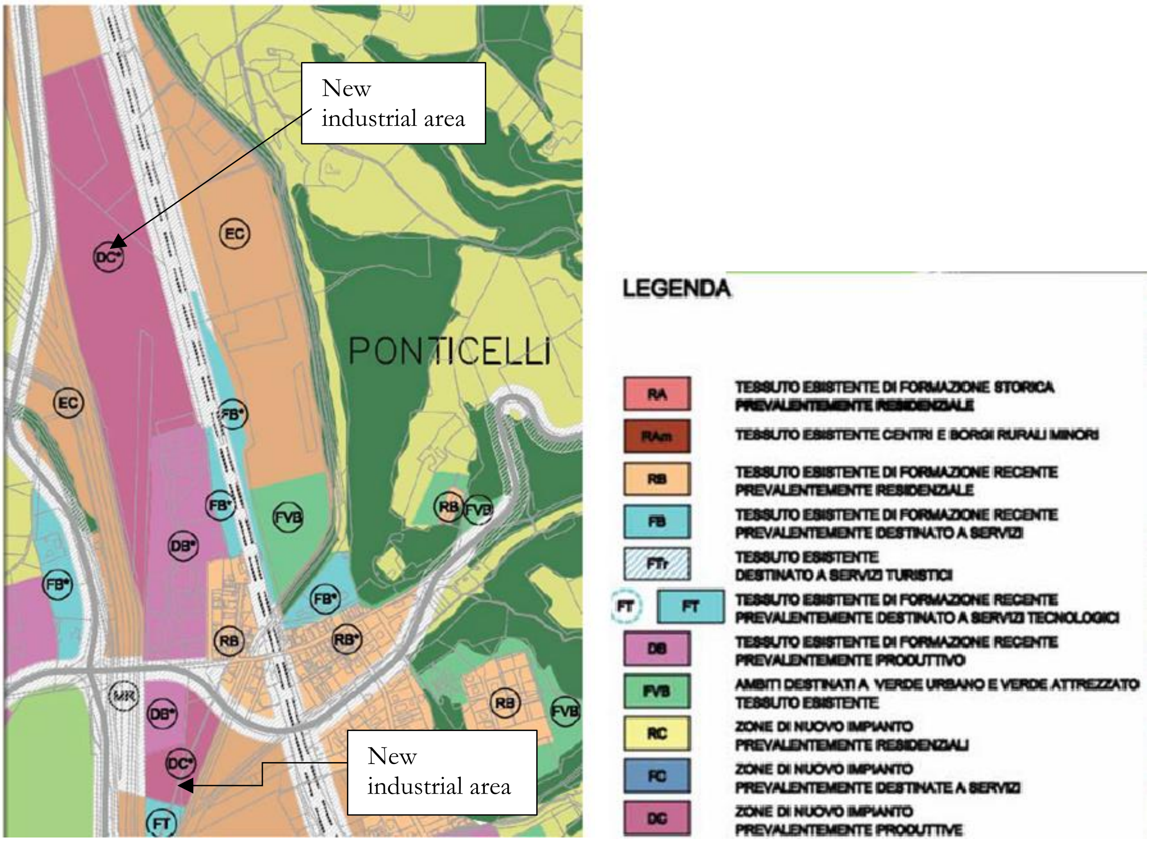


Figure 85 Land use map according to the 2000 modification urban plan (source: Variante P.R.G. 2000).

The rest of the map is missing. Most probably, the industrial area was also enlarged where there is the P.I.P (Plan of Public Initiative), which in 1998 was agricultural.

Piano attuativo di Iniziativa Pubblica (P.I.P.) (Variante P.R.G.) 2002

A Plan of Public Initiative (P.I.P., Piano attuativo di Iniziativa Pubblica) was adopted in 2002, as a variant/modification to the local plan (P.R.G.) for the development of an industrial area (Figure 86).

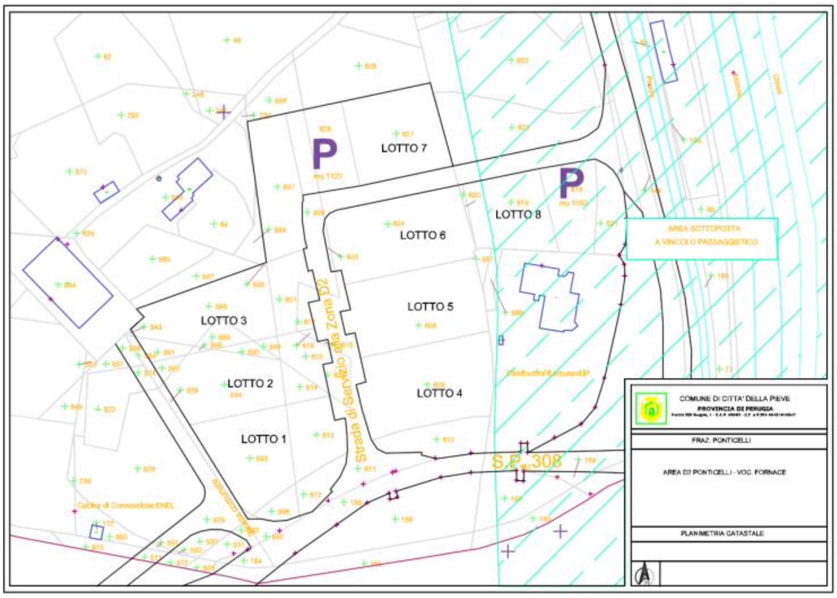


Figure 86 Area included in the operational instrument "Piano Attuativo" (P.I.P.) of 2002 (source: Deliberazione della Giunta Comunale n. 76-2016).

Land-use Map Analysis in Ponticelli

The area addressed in the P.I.P 2002 (Figure 86) was not originally foreseen as industrial in the P.R.G. of 1998, which in fact indicated this zone as agricultural. This area most probably was added in the "variation" of the urban plan (*Variante P.R.G.*) of the year 2000.

Structural Part of Local Plan (P.R.G. Parte Strutturale) 2011

A new urban local plan was proposed for Citta' della Pieve, the first one since the approval of the 1998 plan. This new plan was divided between a "structural" and an "operational" part. These parts were developed separately, and different versions exist over the years (the approval process is often long).

Land-use Map Analysis in Ponticelli

Figure 87 shows the land use map of the Structural Part of the Plan of 2011. "DB" zones indicate existing urban fabrics of recent formation, predominantly productive. Zones "FB*" correspond to the existing urban fabric of recent development, predominantly for services. "DC" indicate zones for new industrial expansion.

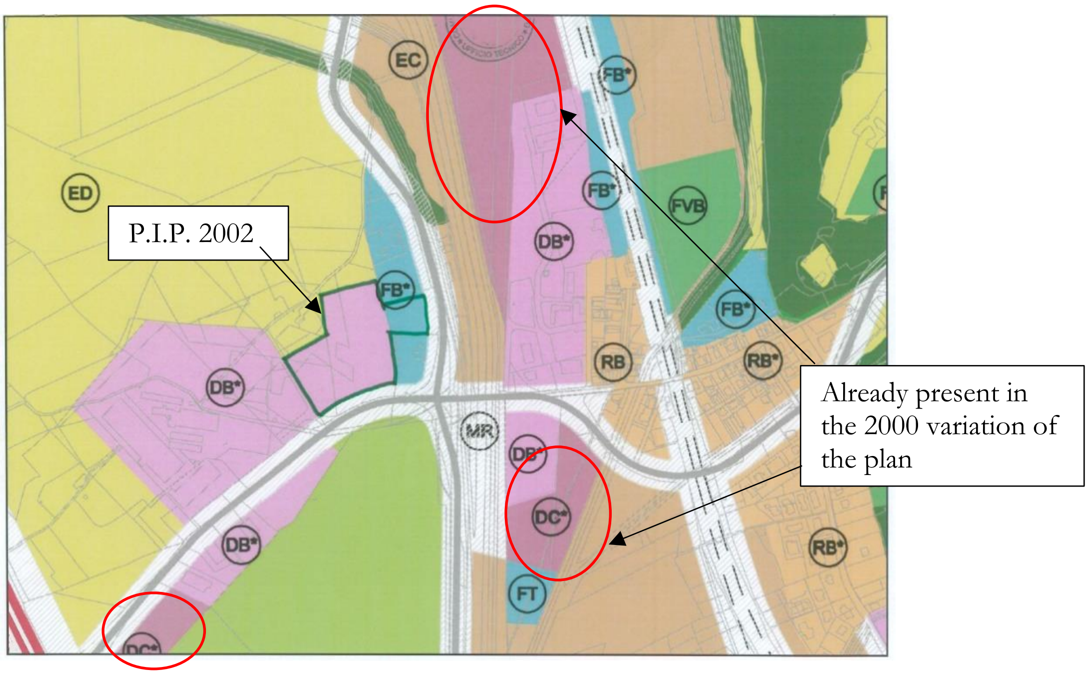


Figure 87 Piano Regolatore Generale Parte Strutturale, 2011 (source: Relazione Illustrativa, Delibera Comunale N. 58-2012).

Partial Modification of the Local Plan (Variante Parziale P.R.G.) 2013

This new modification was motivated by the lack of allocation of some of the parcels defined by the 2002 P.I.P. for the industrial area. It recognised the need to be able to expand the possibility of locating various activities, which are compatible with each other, and thus to incentivize the allocation of the remaining lots through the approval of a partial variant to the P.R.G.

Land-use Map Analysis in Ponticelli

The municipality had invested in the construction of roads, public parking lots and public lighting in order to serve this area. The use of this zone was modified with this new "partial modification" from industrial to commercial/small industries/handicraft to encourage the localization of these activities, which are in line with existing ones in Ponticelli. The modification also states that the size of the lots was not suitable for industrial use. This document states as well that the area has no constraints in terms of flood hazard regulations. It only mentions the 150m protection band, which intersects a "small portion" of the zone.

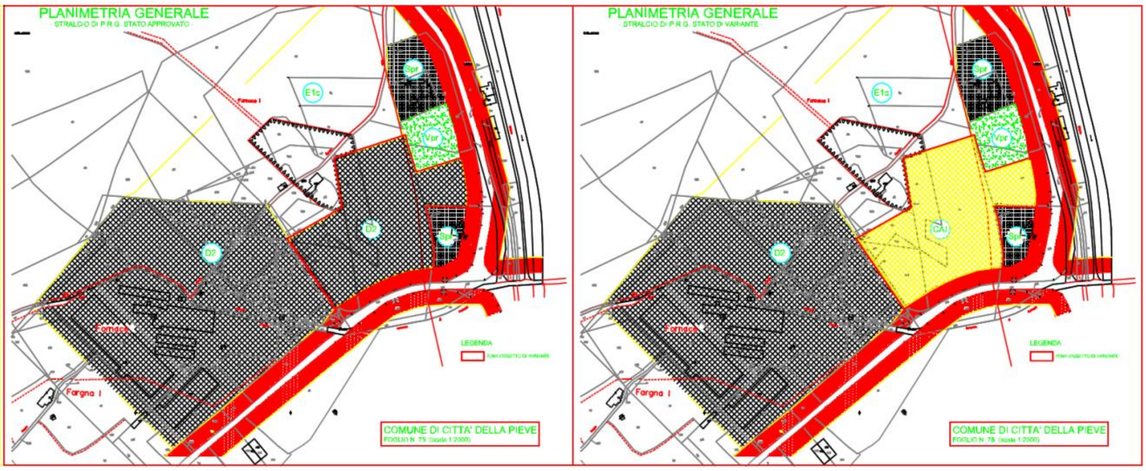


Figure 88 Variante Parziale al P.R.G. 2013 (source: Delibera Comunale N. 55-2013).

The text of the Variant reads that since the P.I.P. in question was approved in the year 2002 and, therefore, before the adoption of P.R.G. structural part (2011), norms defined in the P.R.G. 2011 are not applicable, either the ones regarding flood risk. In any case, the municipality has the responsibility to demand to put in place suitable design solutions relating to the building interventions aimed at reducing flood risk.

Structural Part of Local Plan (P.R.G. Parte Strutturale) 2016

A new structural part of the local plan was adopted in 2016. This is the last version of the plan as for today, 2018.

Land-use Map Analysis in Ponticelli

The new urban plan "structural part" of 2016 introduces in Ponticelli some important changes in land use. In particular, some of the areas allocated in the previous plans for new industrial use were changed back to agriculture (Figure 89).

The P.R.G. identifies the areas subject to hydraulic risk as defined by the existing Tiber Basin Plan (P.A.I). and the Hydraulic Geological Study in support of the P.R.G. The flood hazard and risk map from the First Update of the P.A.I. was included. The P.R.G. states that areas falling within flood-prone zones must follow the P.A.I. Technical Norms that immediately prevail over the ones of the P.R.G. It further states that Implementation Plans of public (like the P.I.P), mixed or private initiative, approved before the adoption of the present plan, retain their validity, even if they are in conflict with what is foreseen by the Plan and the relative norms.

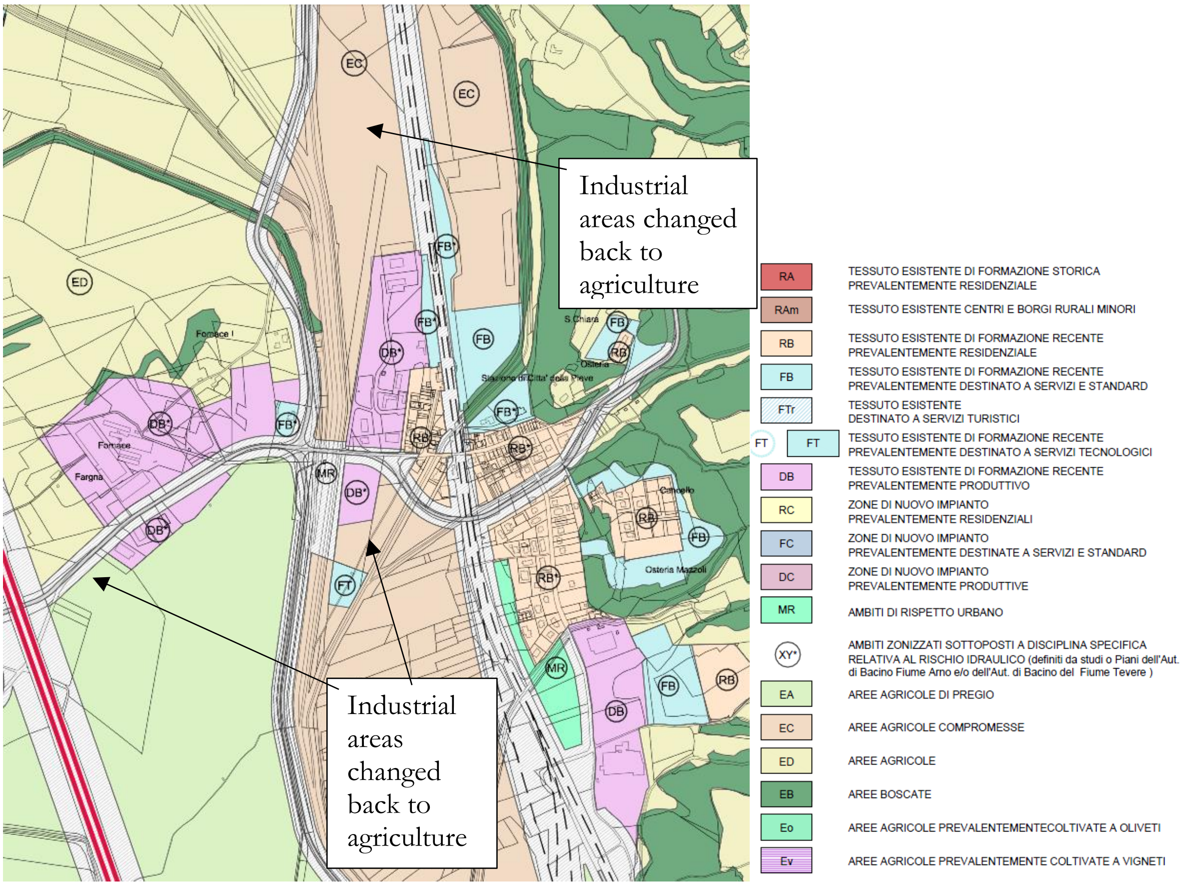


Figure 89 Land use map in the P.R.G. Strutturale 2016 (source: P.R.G. Citta' della Pieve 2016).

Operational Part of Local Plan (P.R.G. Parte Operativa) 2017

The land use map present in the "operational part" of the P.R.G., in contrast to the one contained in the "structural part", shows only the urban area and provides more details within each of the zones. For instance, within the industrial areas, it distinguishes between areas to be completed, areas of new development and areas that already have an operational instrument in place ("strumento urbanistico attuativo operante").

Land-use Map Analysis in Ponticelli

Figure 90 shows more in detail the area corresponding to the already described instrument, the "Piano Attuativo di iniziativa Pubblica" (P.I.P.) of 2002.

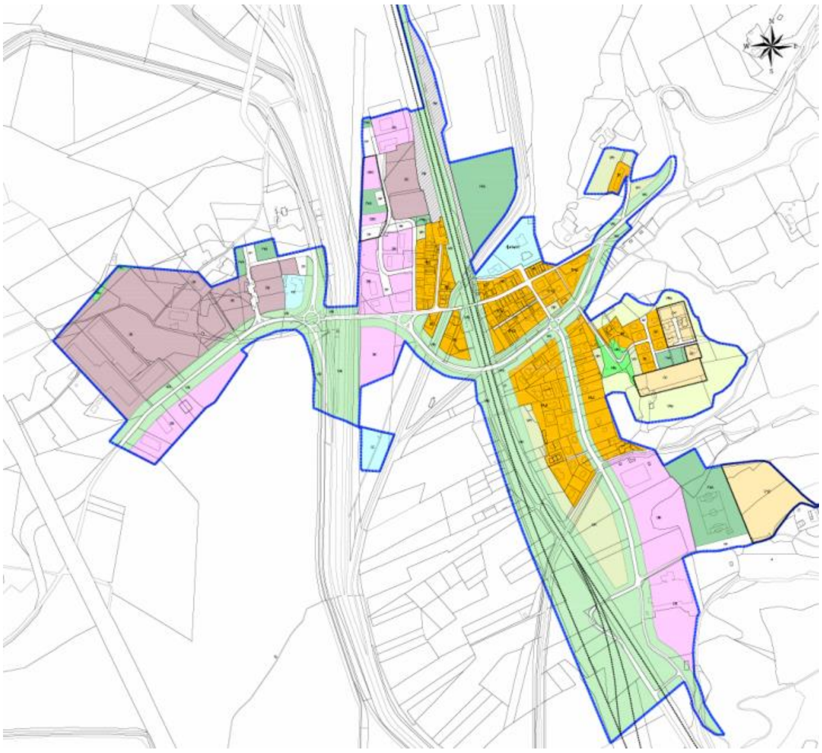


Figure 90 Land use map in the P.R.G. Operativo 2017 (source: P.R.G. Citta' della Pieve 2017).

The Plan makes reference to the P.A.I. indicating that in areas included among the P.A.I "bands" the interventions envisaged by the P.R.G are allowed in respect of the limitations and restrictions imposed by the Technical Norms of the P.A.I. However, this is not respected in practice, as shown by the availability of municipal lots destined for new industrial development (Figure 91). Figure 92 shows the municipal lots that were assigned an economic value for concession in 2016.

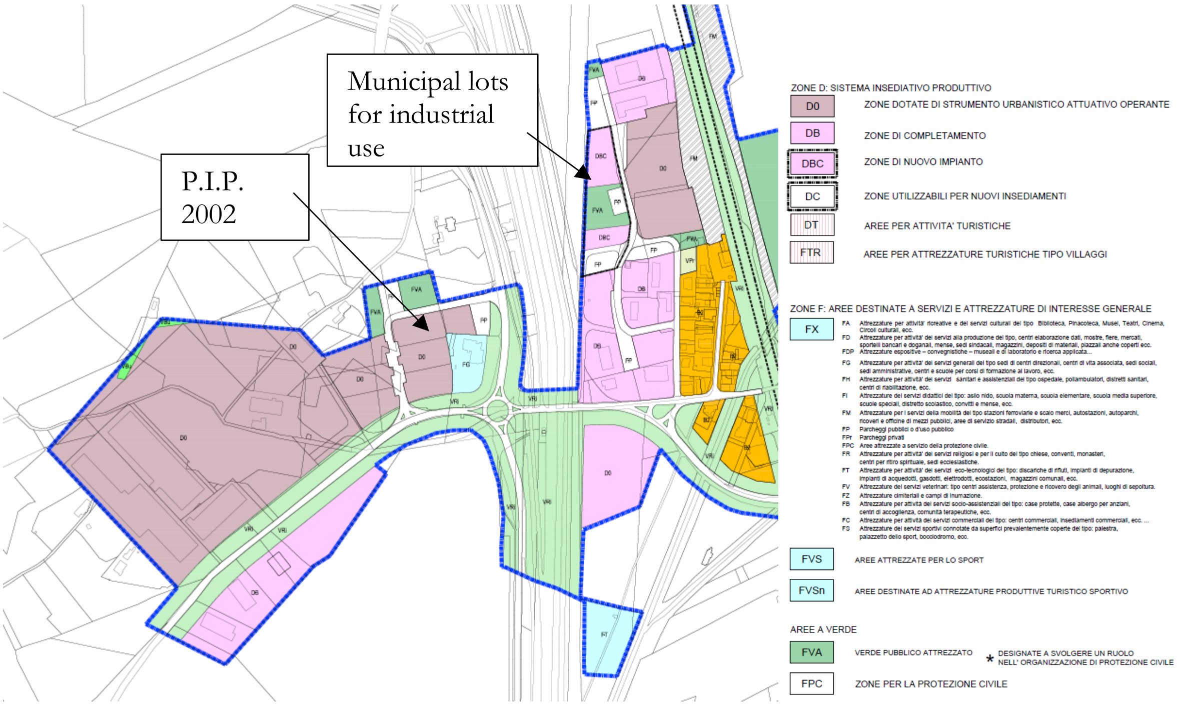


Figure 91 Industrial area in Ponticelli, indicating the zone of the "Piano Attuativo di iniziativa Pubblica" (P.I.P.) of 2002 and municipal lots for new industrial activities (source: P.R.G. Parte Operativa 2017).

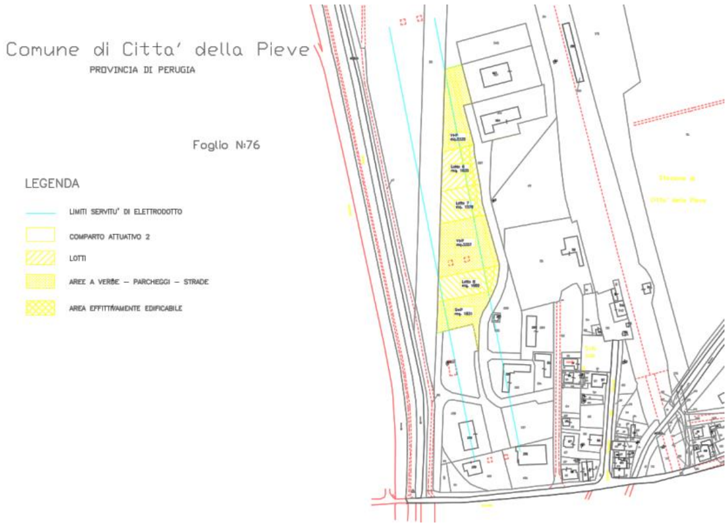


Figure 92 Municipal lots destined for new industrial development (source: Deliberazione della Giunta Comunale n. 76-2016).

6.3.2.3 Comparison between changes in Exposure, Local Urban Plans and Basin Plans

This part of the analysis is based on two different kinds of comparisons, as indicated in Figure 93. The first comparison, shown with orange arrows, aims at answering whether changes in the built environment were foreseen in local urban plans. The second comparison, with turquoise arrows, aims at revealing if local plans comply with the norms in the basin plans in force. In addition, whether urban development complied with Basin Plans. These results are synthesised in Table 46.

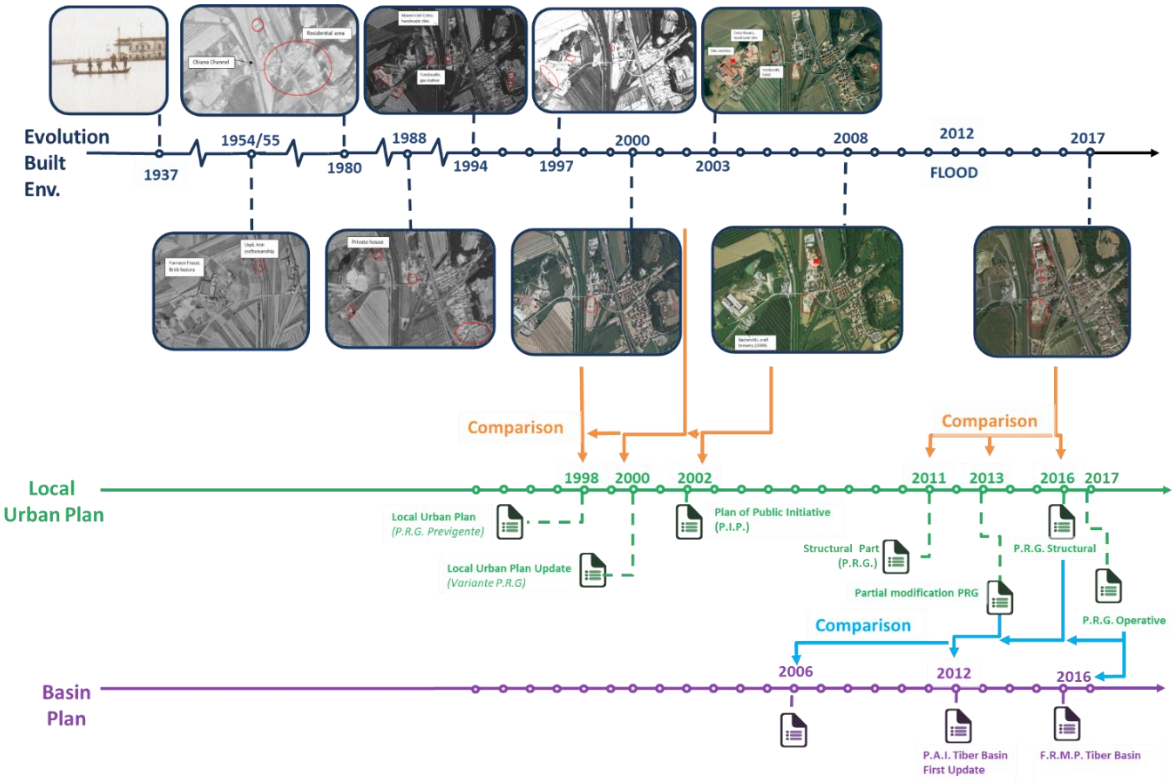


Figure 93 Ponticelli Case Study, Investigation of spatial planning role in shaping disaster risk, Comparisons (source: author).

The orthophoto of the year 2000 (Figure 77) shows the initiation of works for the construction of new urban infrastructure in the south of the provincial road. This area was not foreseen as industrial nor buildable in the 1998 urban plan (P.R.G.). In fact, it was defined as industrial in that same year (2000) in the modification of the urban plan (Figure 85). The new buildings introduced by 2003 (Figure 78), i.e. the hotel and the document management company, were in line with what was expected from the land-uses defined in the 1998 urban plan (i.e. service and industrial use, respectively).

Table 46 Results of Comparisons of Analyses in Ponticelli (source: author).

Questions	**Locality**
	Ponticelli
Were changes in the built environment foreseen in local urban plans?	Yes. All the changes in the built environment were foreseen in local urban plans.
Do Local Urban Plans comply with the norms of the Basin Plans?	Partially. Norms of basin plans do not apply to some planning instruments already in force.
Has urban development complied with Basin Plans?	No. New building and expansion in band A.

Works for new urban infrastructure in the satellite image of 2013 (Figure 81), are coherent with what was proposed in the 2013 modification of the local plan, which envisaged the expansion of the industrial area at the north of the existing one. These works were also in line with what was defined in the 1998 plan, which proposed to complete the built area of that specific portion.

The construction of a new building in 2013 in the industrial area next to the railways is contrary to the Technical Norms of the First Update of the P.A.I. (2012), which state that in band A it is not possible to build new constructions because they obstruct natural river flow. The expansion of an existing industry shown in the satellite image of 2017 (Figure 82) is in line with the land uses and norms of the Structural Part of the plan of 2016. However, it is contrary to the Technical Norms of the P.A.I., which state that in band A it is not possible to increase either the surface or volume of existing constructions unless approved by the competent authority and mitigation measures are taken. There is no indication of any measures taken. These norms are cited in the 2016 urban plan, which means that this modification or addition of a new building should not have been allowed by the municipality unless in the conditions previously stated.

Given that there were no flood hazard maps, nor risk maps for the area of Ponticelli before the year 2012, with the adoption of the First Update of the P.A.I., the Technical Norms of this plan were not applied retroactively. This means that operational plans already in place, as stated in the 2016 Structural Part of the Plan, are not affected. Consequently, unbuilt areas destined for commercial and industrial activities in the 2002 Plan of Public initiative (P.I.P.) will be built when these lots are assigned. The same situation concerns the other two industrial areas in the north and the south of the provincial road. This will entail an increase of flood exposure and risk in the most hazardous area, the zone with the highest probability of flooding (i.e. band A, P.A.I. and P1 of F.R.M.P).

A positive aspect to note is the land-use transformation of some areas from industrial to agriculture in the 2016 "structural part" of the urban plan. These areas were defined as industrial by the year 2000 and ratified in the 2011 plan. The 2012 flood probably had a positive effect in raising awareness, which was translated into the urban plan.

6.3.3 Orvieto Scalo and Ciconia, Orvieto: Evolution of the built environment and local plan analyses

The method for investigating the role of spatial planning in shaping disaster risk, as part of the disaster forensic investigation, is applied in the localities of Orvieto Scalo (Figure 94) and Ciconia (Figure 95), Orvieto. The *Analysis of the Evolution of the Built Environment* is presented next. The *Local Urban Plan Analysis* in Orvieto follows.

6.3.3.1 Analysis of the Evolution of the Built Environment: Orvieto Scalo

This part of the investigation focuses on understanding changes in the built environment and, thus, on flood exposure, through the analysis of orthophotos and satellite images.

Years 1954/1955

The first available orthophoto of the area dates from 1954-1955 (Figure 96), from the Umbria Region Environmental and Territorial Information System (Sistema Informativo Ambientale e Territoriale). The image shows that there are almost no buildings in the area of what would then be Orvieto Scalo, near the Orvieto train station and railways. The historic centre of Orvieto is also shown.

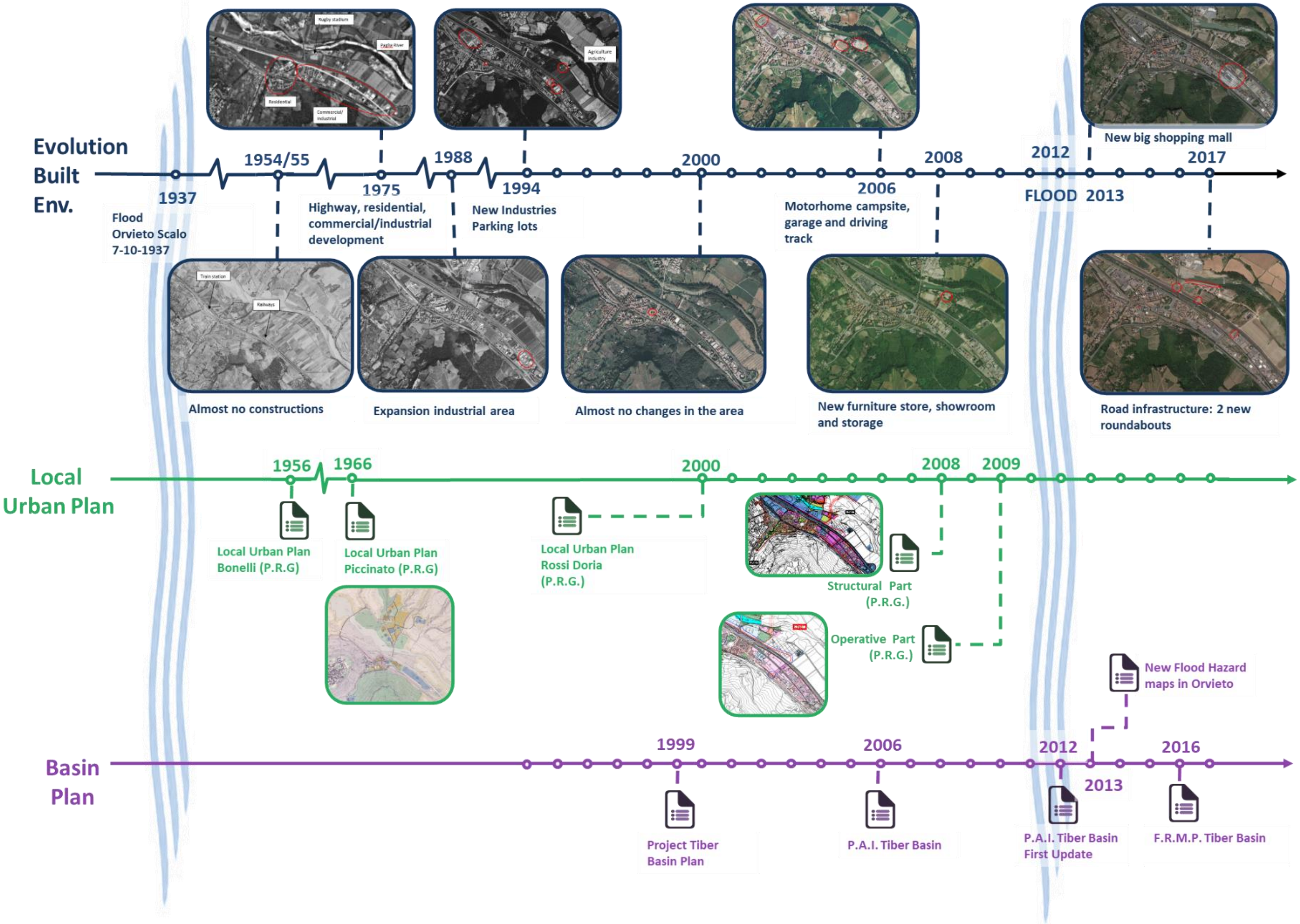


Figure 94 Orvieto Scalo Case Study, Disaster Forensic Investigation: Investigation of spatial planning role in shaping risk (source: author).

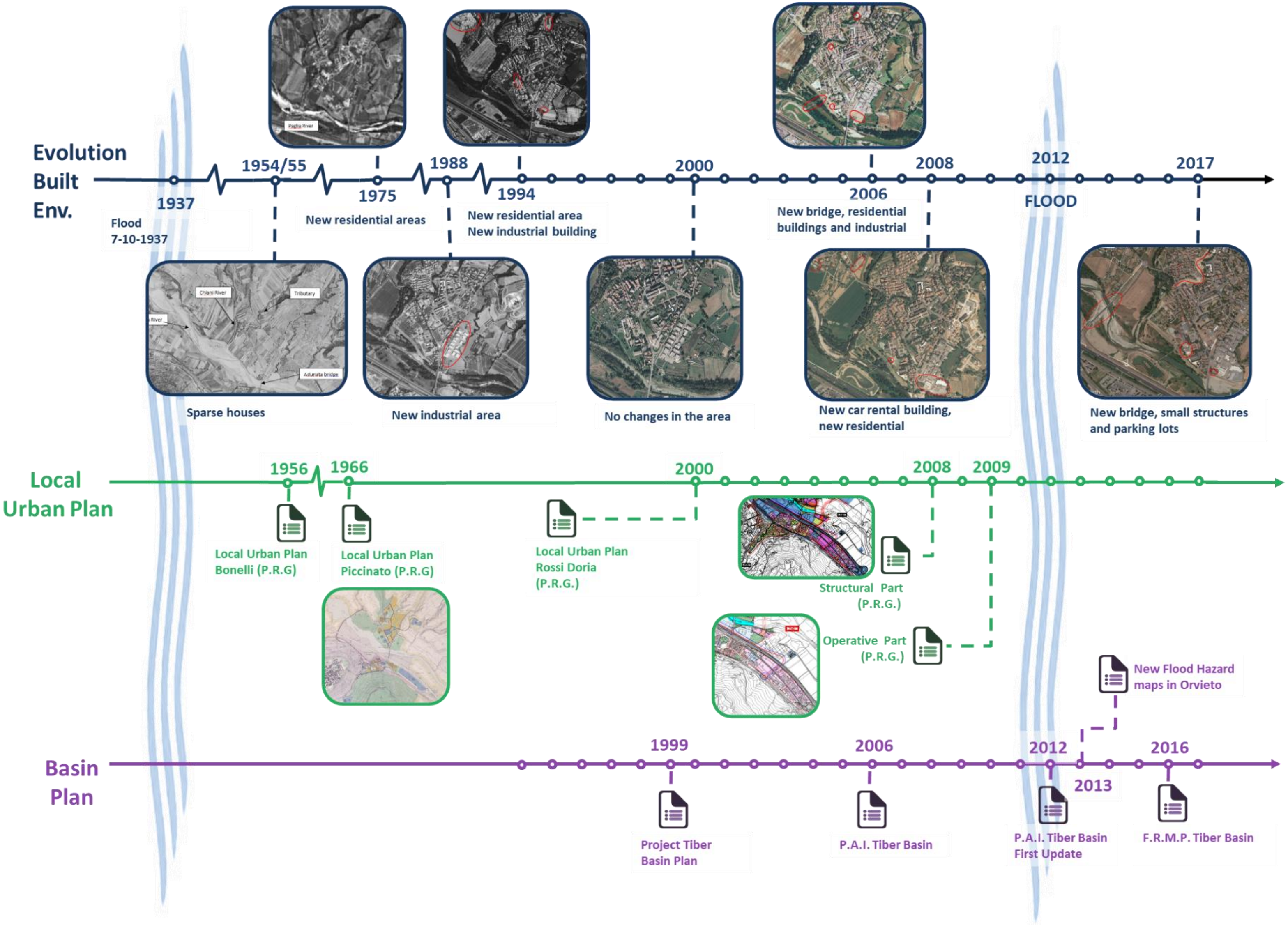


Figure 95 Ciconia Case Study, Disaster Forensic Investigation: Investigation of spatial planning role in shaping risk (source: author).

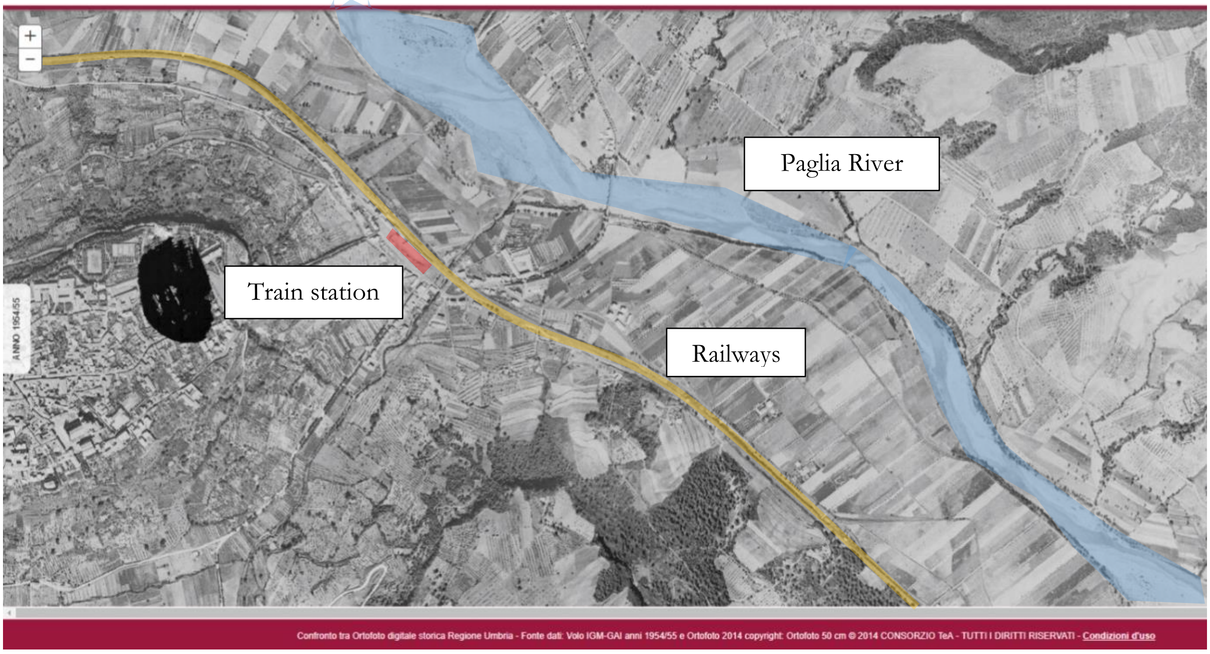


Figure 96 Orthophoto of Orvieto Scalo in 1954/1955 (source: http://siat.regione.umbria.it/paesaggineltempo/).

Year 1975

The next available orthophoto dates from 1975, from the U.S. Geological Survey (Figure 97). Important changes occurred in these 20 years. The presence of the highway, parallel to the Paglia River, as well as several new buildings, give configuration to what Orvieto Scalo looks like today. They are both for residential and commercial/industrial use, as well as the rugby stadium, still present today (2018).

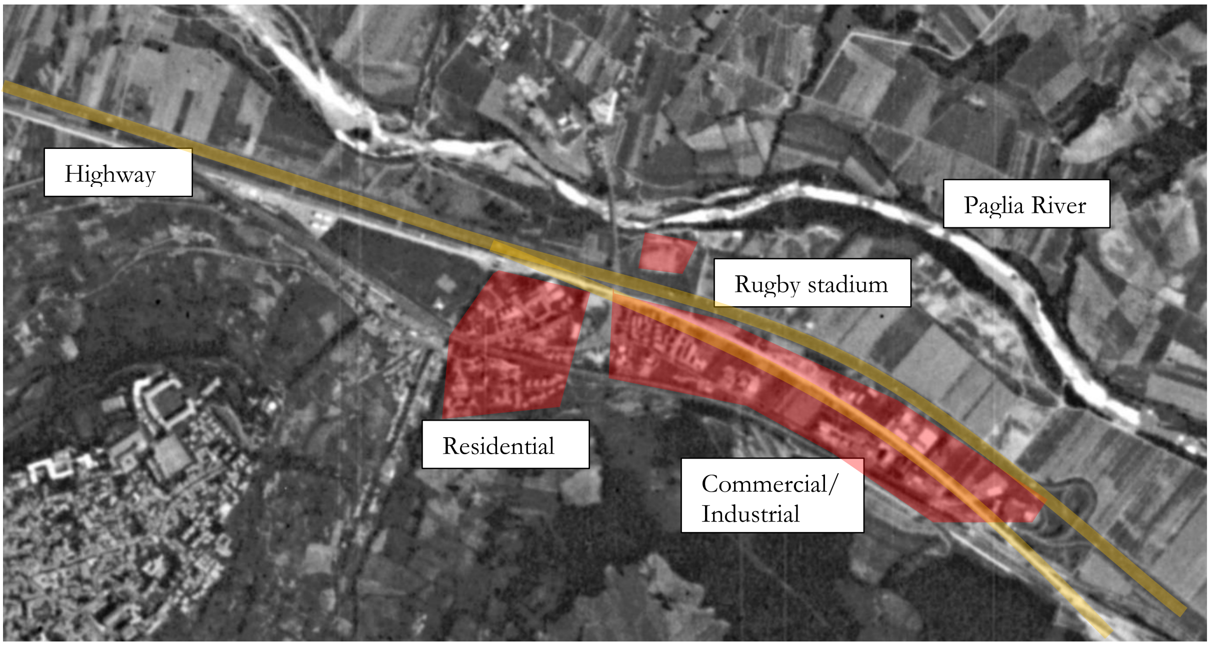


Figure 97 Orthophoto of Orvieto Scalo in 1975 (source: https://earthexplorer.usgs.gov/).

Year 1988

The following orthophoto dates from 1988, available at the national geo-portal of the Italian Ministry of Environment (Figure 98). The image shows the construction of new industrial buildings, next to the access to the highway.

Figure 98 Orthophoto of Orvieto Scalo in 1988 (source: http://www.pcn.minambiente.it/viewer/).

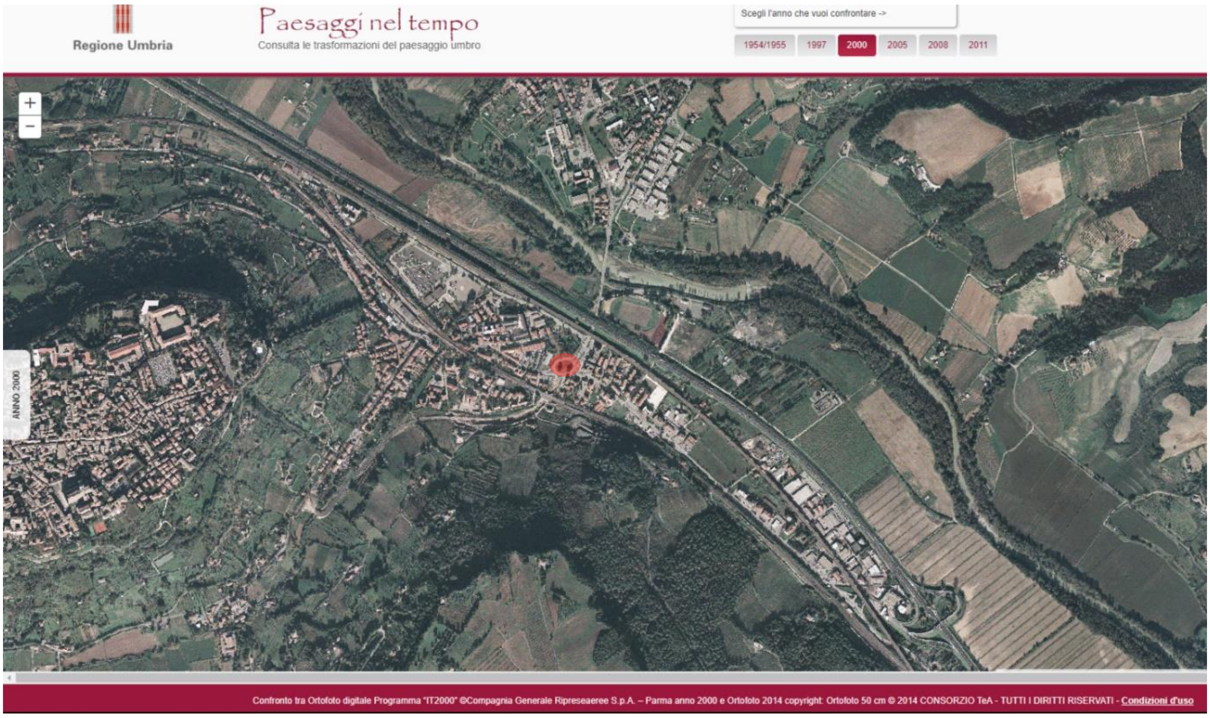
Year 1994

The 1994 orthophoto (Figure 99) shows that new parking lots were built near the train station. One building was added in the residential area, while several industrial ones were established next to the highway, in the commercial/industrial area. An industrial building for the agricultural sector was built between the highway and the Paglia River.

Figure 99 Orthophoto of Orvieto Scalo in 1994 (source: http://www.pcn.minambiente.it/viewer/)

Years 1994, 2000 and 2006

There were not many changes between the years 1994, 2000 (Figure 100) and 2006 (Figure 101). It is relevant to mention the construction of a motorhome campsite next to the Orvieto train station, as well as the beginning of the construction of what in 2008 (Figure 102) became a furniture store and a garage for car repairing. A closed track was built for driving lessons next to the garage.



Confronto tra Ortofoto digitale Programma "IT2000" ©Compagnia Generale Ripreseaeree S.p.A. – Parma anno 2000 e Ortofoto 2014 copyright Ortofoto 50 cm © 2014 CONSORZIO TeA - TUTTI I DIRITTI RISERVATI - Condizioni d'uso

Figure 100 Orthophoto of Orvieto Scalo in 2000 (source: http://siat.regione.umbria.it/paesaggineltempo/)

Figure 101 Orthophoto of Orvieto Scalo in 2006 (source: http://www.pcn.minambiente.it/viewer/).

Figure 102 Orthophoto of Orvieto Scalo in 2008 (source: http://siat.regione.umbria.it/paesaggineltempo/).

Years 2008 and 2012

No changes can be seen in the built environment from 2008 to 2012, as evidenced by the orthophoto from the National Geo-Portal by the Ministry of the Environment (Figure 103).

Figure 103 Orthophoto of Orvieto Scalo in 2012 (source: http://www.pcn.minambiente.it/viewer/).

Year 2013

The satellite image from Google Earth Pro (Figure 104) shows that in 2013 a shopping mall, with a very big supermarket and 15 stores, was built in the only lot that was free. This structure has also an outdoor parking space for 500 cars.

Figure 104 Orthophoto of Orvieto Scalo in 2013 (source: GoogleEarth Pro).

Year 2017

Changes between 2013 (Figure 104) and 2017 (Figure 105) regard road infrastructure. Two new roundabouts were built between the Paglia River and the highway. Many trees were taken away from the left bank of the Paglia River, in correspondence to the road.

Figure 105 Orthophoto of Orvieto Scalo in 2017 (source: GoogleEarth Pro).

The results of the analysis of the evolution of the built environment for Orvieto Scalo are synthesised in Table 47. It is possible to see that flood exposure grew at a high rate from 1955 to the 1990s. In contrast, from the 2000s up to date the changes were slow, but always towards an increase of flood exposure.

Table 47 Results of the Evolution of the Built Environment Analysis in Orvieto Scalo (source: author).

Locality	**Year**	**Description of Changes in Exposure**	**Changes in Exposure**	**Land uses**
Orvieto Scalo	1954/ 1955	Very few buildings, railways, train station.	Baseline	Residential, agricultural, railways.
	1975	Highway, new railway line, many new residential, commercial and industrial buildings, rugby stadium.	(+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area.
	1988	New industrial buildings.	(+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area.
	1994	New parking lot, industrial and agriculture buildings.	(+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2000	Almost no changes in the built environment.	(=)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2006	Motorhome campsite near the train station.	(=+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2008	Two new commercial buildings.	(+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2012	No changes in the built environment.	(=)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2013	Important new shopping mall with outdoor parking space.	(+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.
	2017	Minor changes in road infrastructure.	(=+)	Residential, commercial, industrial, agricultural, highway, railways, sports/green area, parking area.

6.3.3.2 Analysis of the Evolution of the Built Environment: Ciconia

Years 1954/1955

The first available orthophoto of the area dates from 1954-1955 (Figure 106), from the Umbria Region Environmental and Territorial Information System (Sistema Informativo Ambientale e Territoriale). There were almost no buildings in the area of Ciconia, just some sparse small houses.

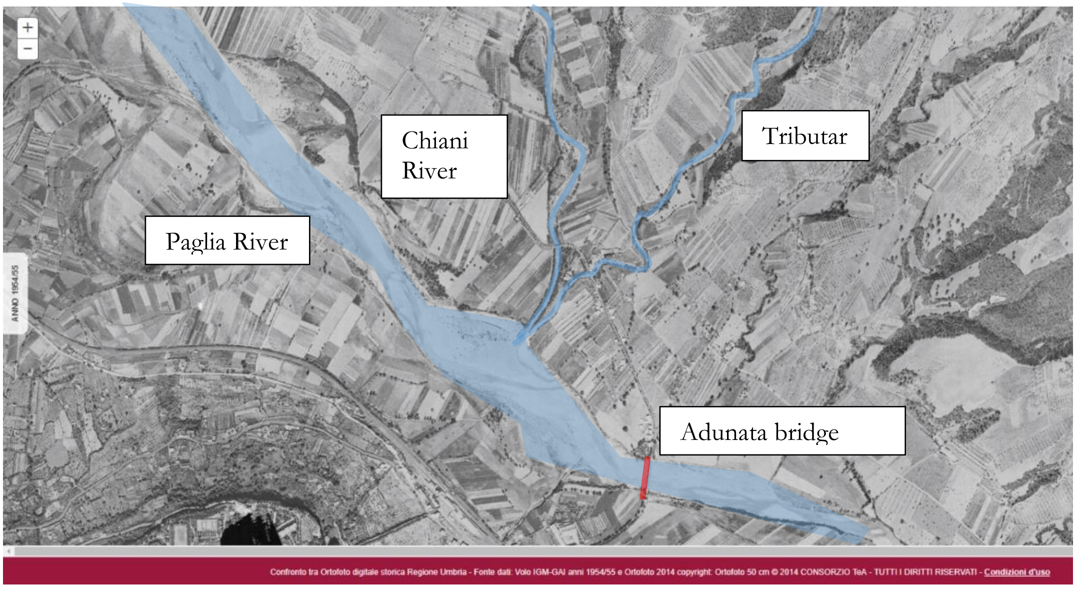


Figure 106 Orthophoto of Ciconia in 1954/1955 (source: http://siat.regione.umbria.it/paesaggineltempo/).

Years 1975 and 1980

The next available orthophoto dates from 1975, from the U.S. Geological Survey (Figure 107). Important changes occurred in these 20 years, which gave rise to the Ciconia locality. Many new buildings appeared, constituting residential areas in the left bank of the Chiani River and around a tributary of the Paglia River. The orthophoto from 1980, also from the U.S.G.S., shows that many buildings were constructed in these new residential areas, as well as at the left bank of the Paglia River.

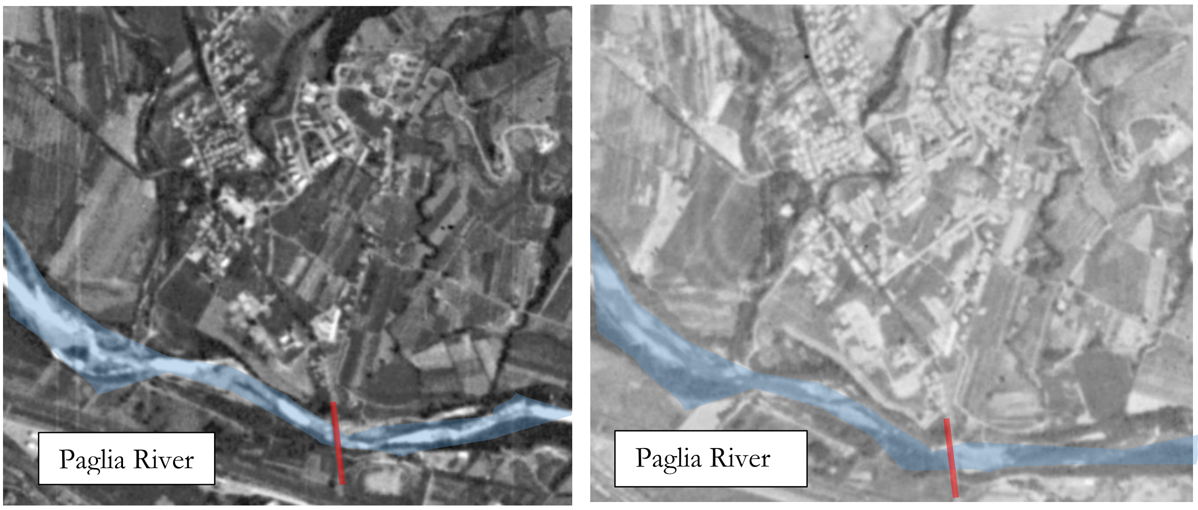


Figure 107 Orthophoto of Ciconia in 1975 (left) and in 1980 (right) (source: USGS, Declassified data 2002).

Year 1988

The following orthophoto dates from 1988, available at the national geo-portal of the Italian Ministry of Environment (Figure 108). A new industrial area was built in Ciconia, near the Adunata Bridge.

Figure 108 Orthophoto of Ciconia in 1988 (source: http://www.pcn.minambiente.it/viewer/).

Year 1994

The 1994 Orthophoto (Figure 109) shows the development of a new residential area at the North, with multifamily houses and some shops/restaurants. Moreover, some residential buildings were added, as well as an industrial one.

Figure 109 Orthophoto of Ciconia in 1994 (source: http://www.pcn.minambiente.it/viewer/).

Year 2006

There were no significant changes in the built environment from the year 1994 until 2006 (Figure 110). A new pedestrian bridge was built crossing the Paglia River. Some new residential buildings were constructed, as well as an industrial one, near the Adunata bridge, in the Paglia riverbank. This new industrial building in Ciconia hosts the technology industry “Electrolink”. Figure 111 shows two orthophotos of the industrial area from the Umbria Region Information System, of the years 2008 and 2011. Two new buildings were built between 2006 and 2008. Between 2008 and 2011, a new structure was built that hosts a car rental, with its respective outdoor parking lot.

Figure 110 Orthophoto of Ciconia in 2006 (source: Ministero dell'Ambiente).

Years 2008 and 2011

Figure 111 Zoom industrial area in Ciconia, in 2008 (left) and 2011 (right) (source: Regione Umbria).

Figure 112 shows the 2011 orthophoto for the whole area of Ciconia. It is possible to see also some expansion in the new northern residential area.

Figure 112 Orthophoto of Ciconia in 2011 (source: Regione Umbria).

Year 2017

There were no significant changes until the year 2017, where the satellite image from Google Earth Pro (Figure 113) shows that a new vehicular bridge was built crossing the Paglia River. Two small structures were built to support the existing high school, in the bank of the Paglia River. Vegetation, as well as some existing parking lots, were removed from the banks of the tributary of the Paglia River. A new parking lot was established in the industrial area, next to the Paglia.

Figure 113 Orthophoto of Ciconia in 2017 (source: GoogleEarth Pro).

The results of the analysis of the evolution of the built environment for Ciconia are synthesised in Table 48. It is possible to see that flood exposure grew at a high rate from 1955 to the 1990s. In contrast, from the 2000s up to date the changes were slower, but always towards an increase of flood exposure.

Table 48 Results of the Evolution of the Built Environment Analysis in Ciconia (source: author).

Locality	**Year**	**Changes in Exposure**	**Changes in Exposure**	**Land use**
Ciconia	1954/ 1955	Sparse small houses, Adunata bridge.	Baseline	Residential, agricultural.
	1975	New residential areas.	(+)	Residential, agricultural.
	1980	Densification of residential areas.	(+)	Residential, agricultural.
	1988	New industrial and commercial area.	(+)	Residential, industrial, commercial and agricultural.
	1994	New residential and commercial area, new residential and industrial buildings.	(+)	Residential, industrial, commercial and agricultural.
	2000	No changes in the built environment.	(=)	Residential, industrial, commercial and agricultural.
	2006	New pedestrian bridge, one new industrial building, two new residential buildings.	(+)	Residential, industrial, commercial and agricultural.
	2008	Two new industrial buildings.	(+)	Residential, industrial, commercial and agricultural.
	2011	One new commercial building and parking lot, two new houses.	(+)	Residential, industrial, commercial and agricultural.
	2017	New vehicular bridge, parking lot.	(=+)	Residential, industrial, commercial and agricultural.

6.3.3.3 Local Urban Plan Analysis, Orvieto

Orvieto Scalo and Ciconia are located in the municipality of Orvieto. Orvieto’s Local urban plans (P.R.G., “Piano Regolatore Generale”) were retrieved and analysed next, with a focus on the land use maps in the areas of Orvieto Scalo and Ciconia. The urban local plans in the municipality of Orvieto are the following:

- Local Urban Plan 1956 (P.R.G.) (written in 1956 by Arch. Prof. Renato Bonelli, adopted in 1958).
- Local Urban Plan 1966 (P.R.G.) (by Arch. Luigi Piccinato)
- Local Urban Plan 2000 (P.R.G.) by Arch. Bernardo Rossi Doria
- Structural and Operational Parts Local Urban Plan 2008/2009 (P.R.G.)

The results of the Local Urban Plan Analysis of the municipality of Orvieto are synthesised in Table 49. Available documents will be explained in detail in the next paragraphs.

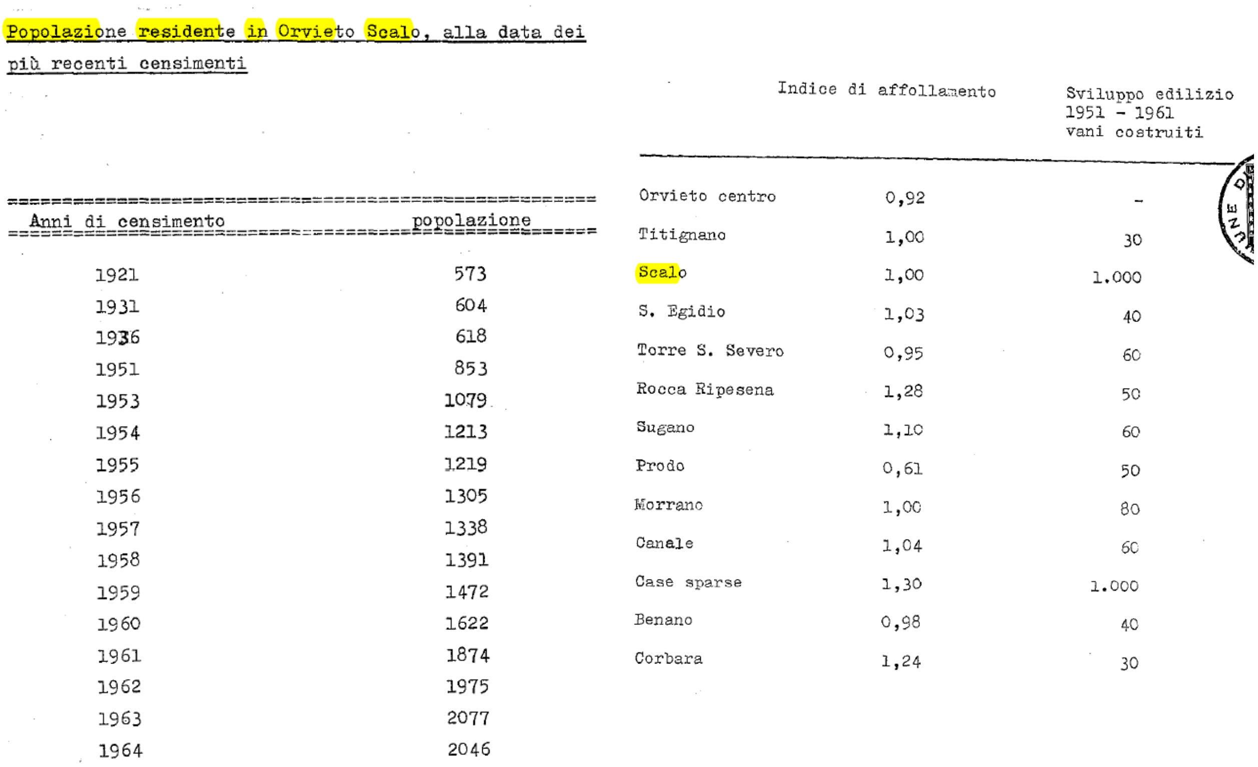
Table 49 Results of the Local Urban Plan Analysis of Orvieto (source: author).

Local Urban Plans Orvieto	**Year**	**Flood hazard considered**		**Locality**	**Land use/future uses**	**Land use changes**
		(Yes/No)	**How?**			
P.R.G. (by Arch. Prof. Piccinato)	1966	Yes	The Civil Engineers Department executed hydraulic works to reduce the hazard next to the Paglia, in Ciconia. Green areas were set next to the river bank.	Orvieto Scalo	New area for reinforcement of existing activities (hotels, inns, stores and warehouses). New area for collective activities. Railways, Highway, provincial road.	Transformation from green area to commercial, services and collective activities.
				Ciconia	Area of Ciconia for urban expansion: services, schools, shopping centres, religious centres, green areas, roads and pedestrian paths. Green areas at the river bank.	Transformation from green area to new urban pole.
P.R.G. Parte Strutturale & Parte Operativa	2008/ 2009	Yes	Mentions the P.A.I and states that norms must be applied. Norms of the Structural Part forbid new construction in narrow areas than comprehend rivers and trenches.	Orvieto Scalo	Existing uses: commercial, industrial, touristic services, general and technological services, small saturated residential area, parking spaces, train station, railways, highway.	-
				Ciconia	Existing industrial area and zones for new industrial development and parking space next to Paglia River. Small area for residential expansion next to Chiani River.	Transformation from green area to industrial.

Local Urban Plan (P.R.G.) 1966 (by Arch. Prof. Piccinato)

The Urban Plan of 1956 by Arch. Bonelli was modified in 1962 and integrated with recommendations that aimed at preserving the historic and environmental characteristics of the area of Orvieto. Nevertheless, these modifications were never enforced, giving rise to numerous new constructions in an irregular way, including offices and schools in Orvieto Scalo, from 1962 to the adoption of the 1966 "Piccinato Plan" (Piccinato, 1966).

Arch. Piccinato analysed changes in the built environment in Orvieto from the year 1921 to 1964 and concluded that the only area that had had a notable development was the one around the railway station, Orvieto Scalo. In addition to the presence of the railway, that of a road junction had also led to the establishment of some craft and manufacturing activities. Likewise, the population of Orvieto Scalo almost quadrupled from 1921 (573 inhabitants) to 1964 (2046 inhabitants) (Figure 114).



Popolazione residente in Orvieto Scalo, alla data dei più recenti censimenti

Anni di censimento	popolazione
1921	573
1931	604
1936	618
1951	853
1953	1079
1954	1213
1955	1219
1956	1305
1957	1338
1958	1391
1959	1472
1960	1622
1961	1874
1962	1975
1963	2077
1964	2046

	Indice di affollamento	Sviluppo edilizio 1951 - 1961 vani costruiti
Orvieto centro	0,92	-
Titignano	1,00	30
Scalo	1,00	1.000
S. Egidio	1,03	40
Torre S. Severo	0,95	60
Rocca Ripesena	1,28	50
Sugano	1,10	60
Prodo	0,61	50
Morrano	1,00	80
Canale	1,04	60
Case sparse	1,30	1.000
Benano	0,98	40
Corbara	1,24	30

Figure 114 Population in Orvieto Scalo from 1921 to 1964 (left) and the number of rooms built in different localities between 1951-1961 (right) (source: Piccinato, 1966).

Regarding Ciconia, Arch. Piccinato stated that only in the last years there had been certain development, with one and two-story houses and a few shops.

According to Arch. Piccinato, the presence of the most important nodes of main communications (railway station, highway and provincial roads) had already made Orvieto Scalo the most important settlement, almost the base point of a new city. Orvieto Scalo could not, however, be considered a real neighbourhood. There were, in fact, many structures of general functions (e.g. hotels, warehouses, craft laboratories) but the resident population, according to the architect, was not proportionate with the economic importance of the site and to what it would have to assume in the near future. A direct expansion was not possible due to lack of buildable areas that would if not ruin the surrounding landscape. Instead, it was necessary according to Arch. Piccinato to go beyond the Paglia River and to create a new "real" urban area. In fact, this is what the P.R.G. of 1966 proposed, to assign the area of Ciconia for urban expansion. The plan foresaw the creation of a "real" urban area with all the services, schools, shopping centres, religious centres, green areas, roads and pedestrian paths. The area immediately next to the river was destined to green spaces: public parks, sports fields, education institutes, playgrounds and walkways.

Floods are mentioned by Arch. Piccinato in the 1966 plan, as follows:

> *We need to dispel any doubts about the weight of the torrential regime of the Paglia that affects the area. In this regard, the recent flood experience of September 1965, and even more that of 1937 (the worst so far) give all assurance. In fact, based on the data of the 1937 flood that brought the level of the water to a maximum altitude never reached before nor after, the Civil Engineers Department has reinforced the left bank of the Chiani River at the confluence with new construction works. At the same time, the Department gave every assurance regarding the entire left bank of the Paglia River between the planned park and the sports field (Piccinato, 1966: 46).*

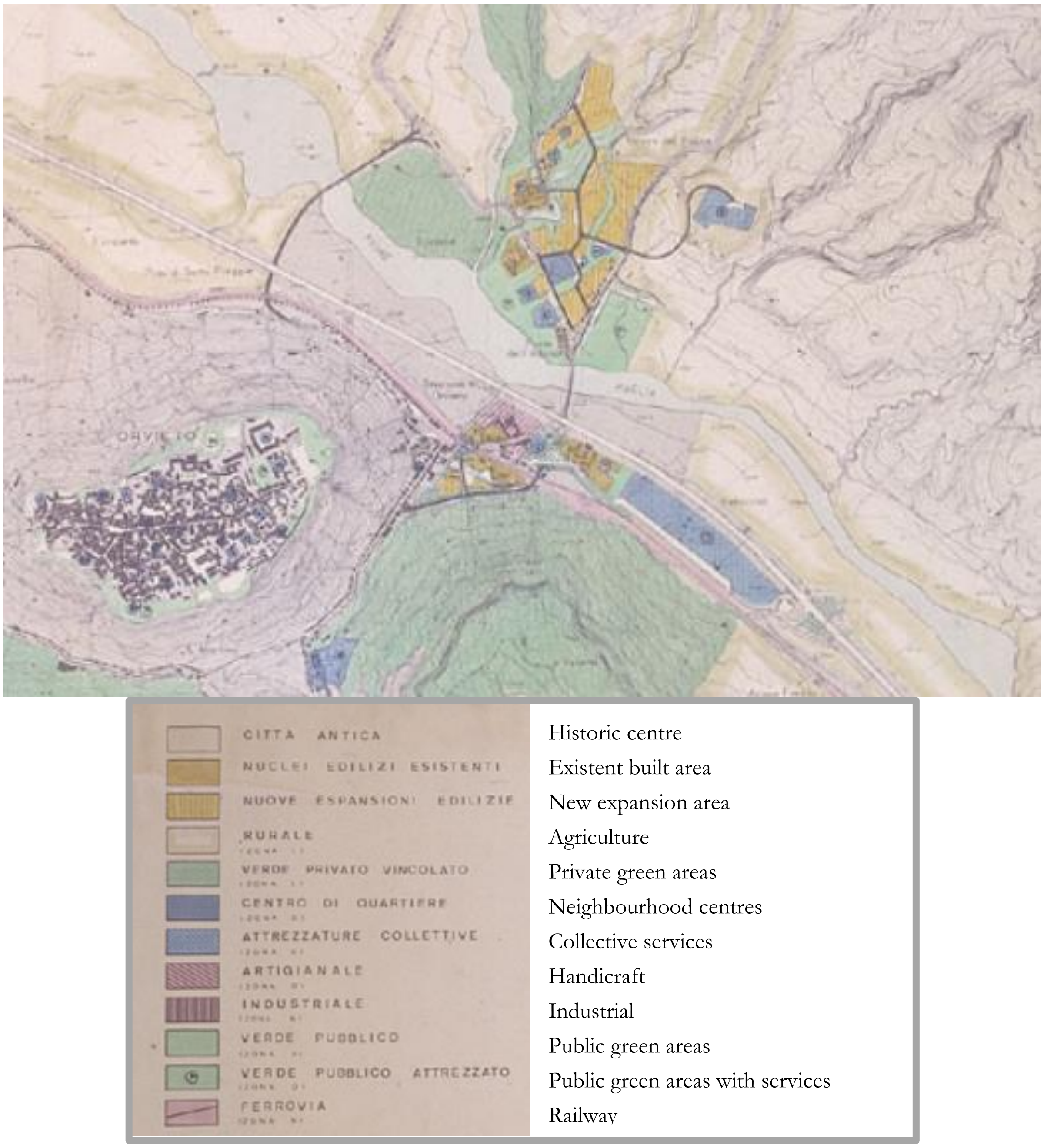
Land-use Map Analysis Orvieto Scalo and Ciconia

The 1966 urban plan proposed to reinforce existing activities already in Orvieto Scalo, i.e. hotels, inns, stores and warehouses. It dedicated a big area to this end in the locality. An education centre of considerable importance was planned on the bank of the Paglia, in the area of Ciconia, for the Technical Institute and an elementary school, both equipped with large green spaces for sports. It is important to note that the area in blue in Orvieto Scalo was destined for collective services open doors. While the white-beige areas indicate agriculture use.

Structural Part of Local Plan (P.R.G. Parte Strutturale) 2008 and Operational Part (P.R.G. Parte Operativa) 2009

The structural and operational parts constitute a unique local urban plan (Piano Regolatore Generale). The P.R.G structural part identifies the specific territorial vocations at the level of general planning in accordance with the objectives and indications of regional and provincial-territorial planning. The P.R.G operational part identifies and regulates the urban planning previsions according to the modalities and the limits established in the structural part.

Regarding the consideration of flood hazard, the structural part mentions that the areas inside the flood-prone areas "A, B and C" defined in the P.A.I. (Piano Stralcio di Assetto Idrogeologico) are subject to the regulations established in that plan. However, it does not cite the restrictions defined in the P.A.I, either it indicates these areas in the land-use maps. There are very narrow areas than comprehend rivers and trenches where new constructions are forbidden, as indicated in the norms of the Structural part of the plan (Article 91).

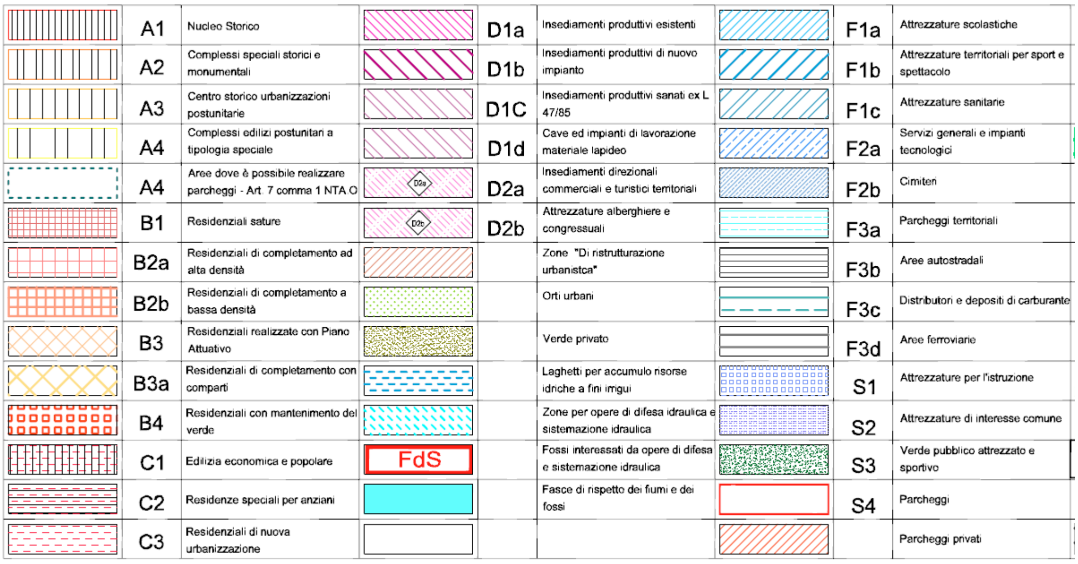


CITTA ANTICA	Historic centre
NUCLEI EDILIZI ESISTENTI	Existent built area
NUOVE ESPANSIONI EDILIZIE	New expansion area
RURALE	Agriculture
VERDE PRIVATO VINCOLATO	Private green areas
CENTRO DI QUARTIERE	Neighbourhood centres
ATTREZZATURE COLLETTIVE	Collective services
ARTIGIANALE	Handicraft
INDUSTRIALE	Industrial
VERDE PUBBLICO	Public green areas
VERDE PUBBLICO ATTREZZATO	Public green areas with services
FERROVIA	Railway

Figure 115 Land use map from the 1966 Local Urban Plan (P.R.G.) (source: Piccinato, 1966).

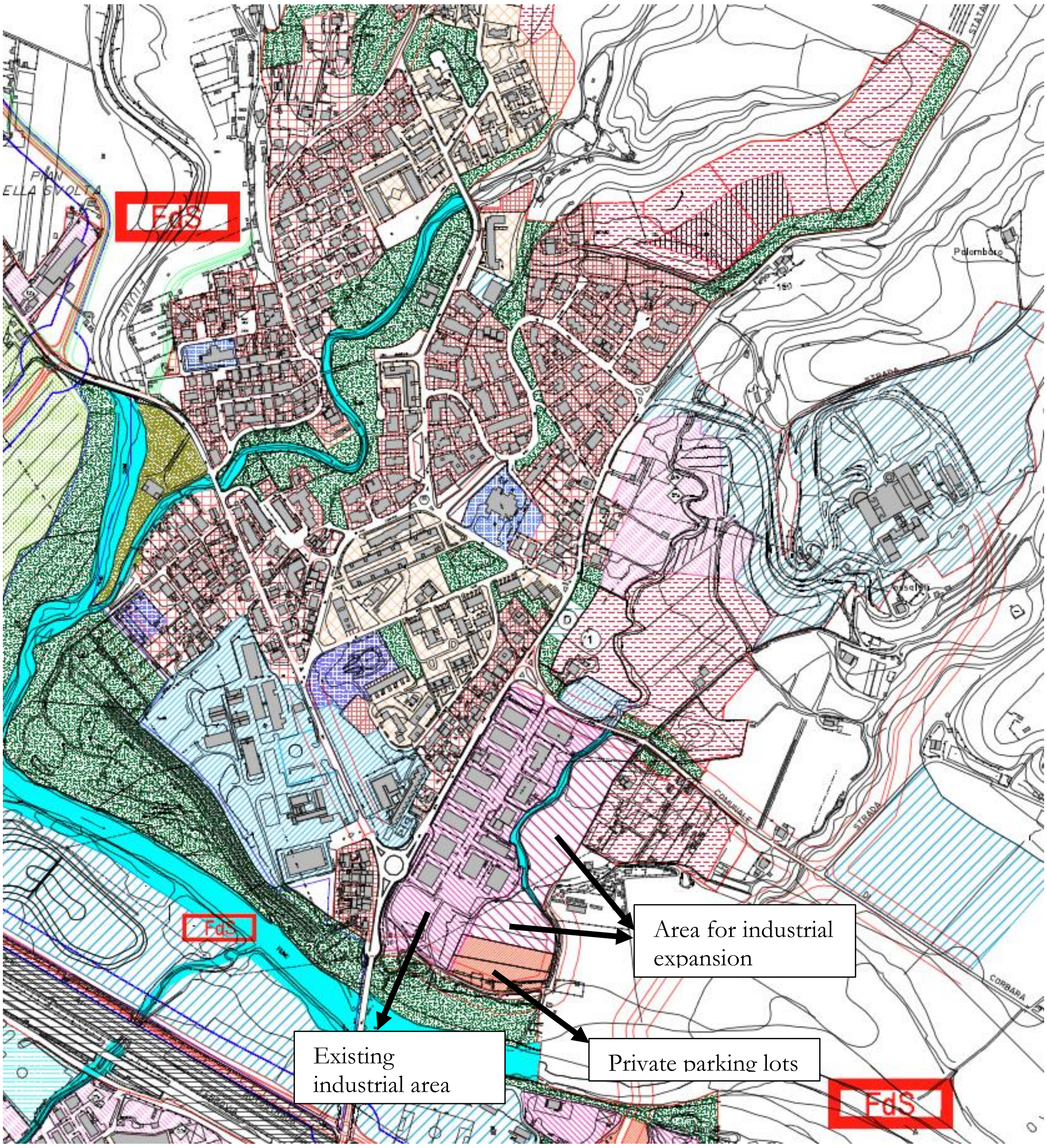
Land-use Map Analysis in Ciconia

The Operational part defines land-use in more detail with respect to the structural part and is, thus, reported next. Figure 117 shows land use in Ciconia near the Paglia River. This land-use map shows the existing industrial area as well as zones for new industrial development and parking space. It is important to note that the area destined for private parking lots is located inside band C of the P.A.I. First Update 2008 (Figure 65) and later in band A, in the 2013 version of the hazard map (Figure 66). A portion of the existing (though not yet built) and of the new industrial areas fall inside P.A.I. band C, according to the 2013 map.



▥	A1	Nucleo Storico	▧	D1a	Insediamenti produttivi esistenti	▨	F1a	Attrezzature scolastiche
▥	A2	Complessi speciali storici e monumentali	▧	D1b	Insediamenti produttivi di nuovo impianto	▨	F1b	Attrezzature territoriali per sport e spettacolo
▥	A3	Centro storico urbanizzazioni postunitarie	▧	D1C	Insediamenti produttivi sanati ex L 47/85	▨	F1c	Attrezzature sanitarie
▥	A4	Complessi edilizi postunitari a tipologia speciale	▧	D1d	Cave ed impianti di lavorazione materiale lapideo	▨	F2a	Servizi generali e impianti tecnologici
☐	A4	Aree dove è possibile realizzare parcheggi - Art. 7 comma 1 NTA O	D2a	D2a	Insediamenti direzionali commerciali e turistici territoriali	▨	F2b	Cimiteri
▦	B1	Residenziali sature	D2b	D2b	Attrezzature alberghiere e congressuali	▤	F3a	Parcheggi territoriali
▦	B2a	Residenziali di completamento ad alta densità	▨		Zone "Di ristrutturazione urbanistca"	▤	F3b	Aree autostradali
▦	B2b	Residenziali di completamento a bassa densità	▒		Orti urbani	▤	F3c	Distributori e depositi di carburante
▩	B3	Residenziali realizzate con Piano Attuativo	▒		Verde privato	▤	F3d	Aree ferroviarie
▩	B3a	Residenziali di completamento con comparti	▤		Laghetti per accumulo risorse idriche a fini irrigui	▦	S1	Attrezzature per l'istruzione
▦	B4	Residenziali con mantenimento del verde	▧		Zone per opere di difesa idraulica e sistemazione idraulica	▦	S2	Attrezzature di interesse comune
▦	C1	Edilizia economica e popolare	FdS		Fossi interessati da opere di difesa e sistemazione idraulica	▒	S3	Verde pubblico attrezzato e sportivo
▤	C2	Residenze speciali per anziani	■		Fasce di rispetto dei fiumi e dei fossi	☐	S4	Parcheggi
▤	C3	Residenziali di nuova urbanizzazione	☐			▨		Parcheggi privati

Figure 116 Operational plan land-use map legend (source: Comune Orvieto, 2011).



Area for industrial expansion

Existing industrial area

Private parking lots

Figure 117 Ciconia land-use map (part 1) of the Operational Urban Plan 2009 (source: Comune Orvieto, 2011).

Figure 118 shows one of the residential zones, including an area with an existing acting plan and areas for "residential completion of high density". These correspond to areas where urbanization "has not been completed" and, therefore, construction is permitted. These areas were originally inside band A of the P.A.I., according to the 2008 flood hazard map, which means that further development was forbidden. However, these areas were changed to band C in 2013, after some hydraulic works were done that mitigated part of the flood hazard. Figure 118 shows as well an area destined for commercial and touristic services, previously classified in the Structural part of the plan as "industrial".

This area was outside the flood-prone area in the 2008 flood hazard map, but in the 2013 version they were classified in band C. Development in band C is allowed, but these areas are still under risk and require prevention and emergency programs and plans.

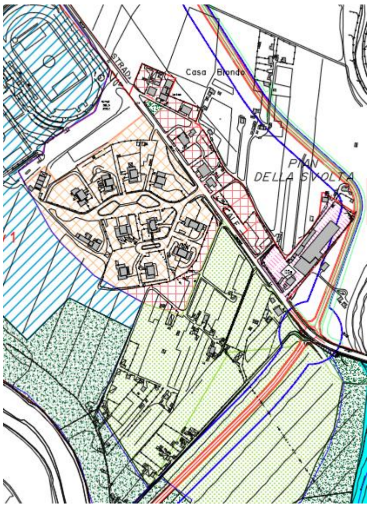


Figure 118 Ciconia land-use map (part 2) of the Operational Urban Plan 2009 (source: Comune Orvieto, 2011).

Moreover, the Operational part introduces a new small residential zone inside the flood-prone area; band C of the P.A.I., next to the Chiani River (Figure 119). This area allows residential use with low-density development.

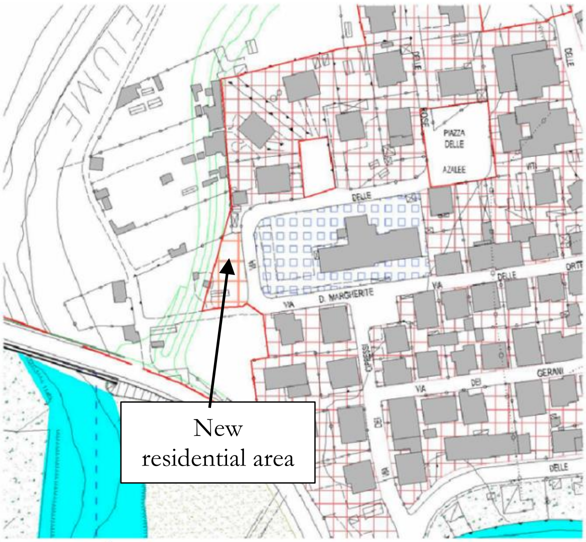


Figure 119 Zoom of land-use map on the new residential area in Ciconia, next to the Chiani River (source: Comune Orvieto, 2011).

Land-use Map Analysis in Orvieto Scalo

Figure 120 and Figure 121 show the land-use map from the Operational part of the local urban plan at the Orvieto Scalo area. The whole area between the Paglia River and the second railways is flood prone, which comprises the majority of Orvieto Scalo. In the first version of the flood hazard maps, this area was not indicated as flood prone. Instead, in the new version in 2013, the whole area was included inside P.A.I. band B. Land uses in Figure 120 in the flood-prone area (until the railways) are mostly parking spaces and commercial and touristic services.

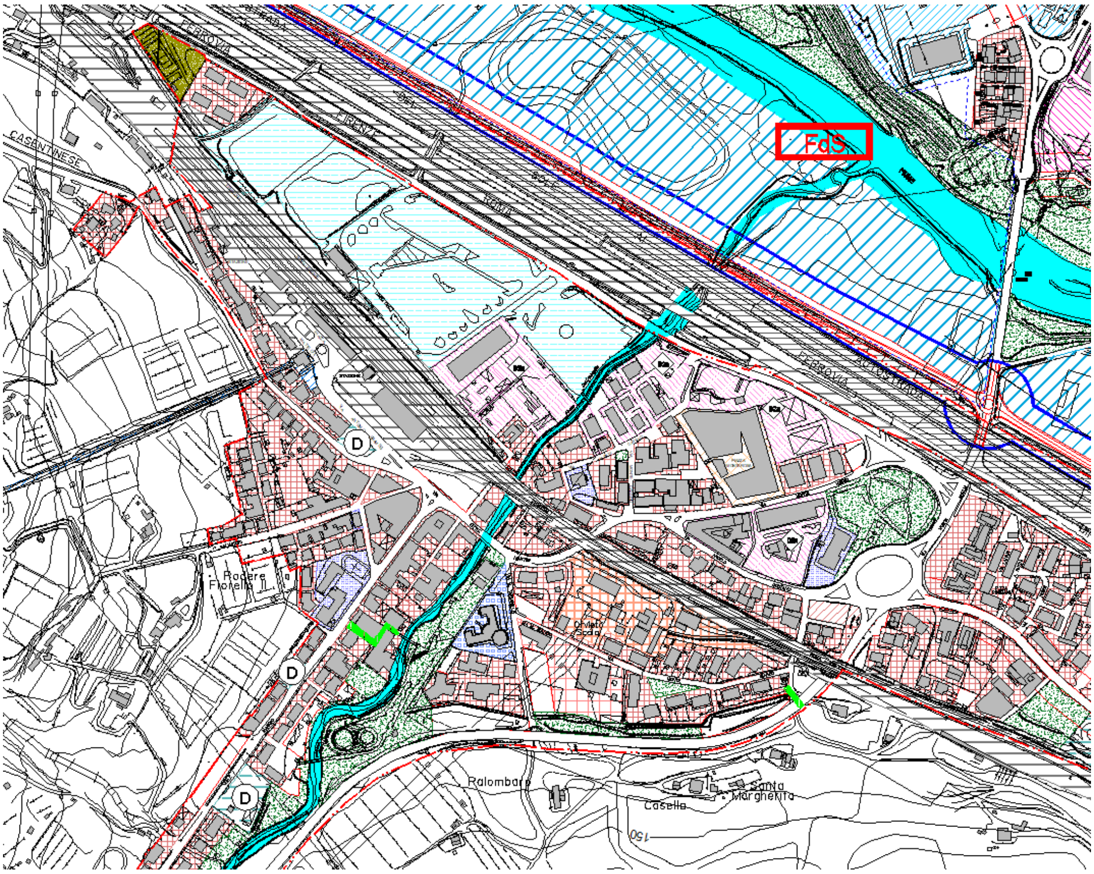


Figure 120 Orvieto Scalo land-use map (part 1) of the Operational Urban Plan 2009 (source: Comune Orvieto, 2011).

Land uses in Figure 121 instead are mostly existing industrial areas and commercial and touristic services, including hotels and museums. A smaller area corresponds to “saturated residential” use, while the rest includes general and technological services and fuel distribution. This part is also inside band B of the P.A.I., in the 2013 version of the map.

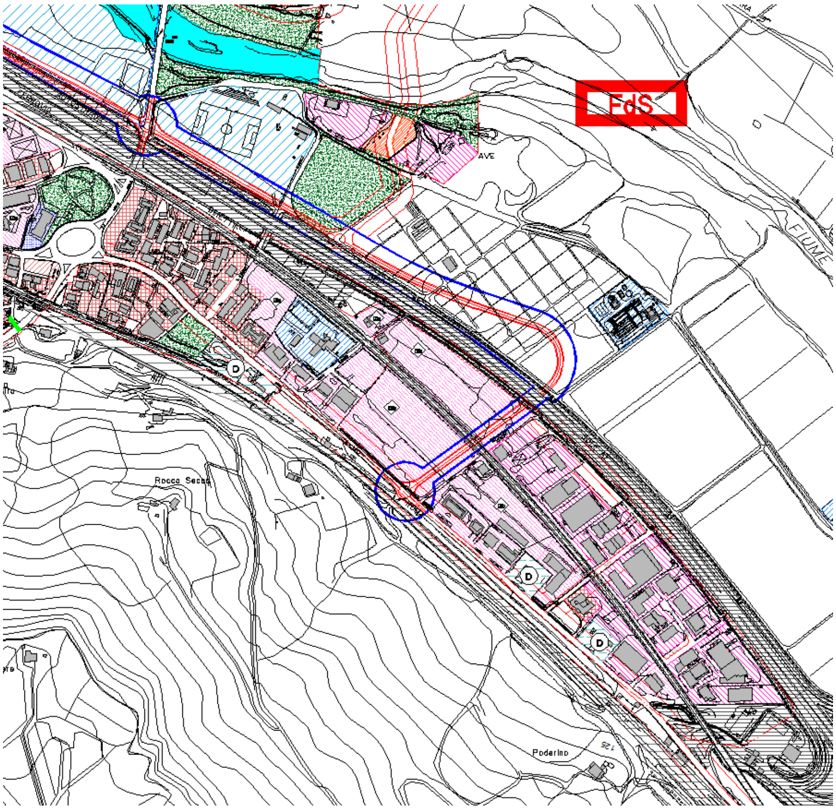


Figure 121 Orvieto Scalo land-use map (part 2) of the Operational Urban Plan 2009 (source: Comune Orvieto, 2011).

6.3.3.4 Comparison between changes in Exposure, Local Urban Plans and Basin Plans

This part of the analysis is based on two different kinds of comparisons, as indicated for example in Figure 122 for Orvieto Scalo. The first comparison, shown with orange arrows, aims at answering whether changes in the built environment were foreseen in local urban plans. The second comparison, with turquoise arrows, aims at revealing if local plans comply with the norms in the basin plans in force. In addition, whether urban development was in line with norms in Basin Plans. These results are synthesised in Table 50.

The 1954/55 orthophoto in the area of Orvieto Scalo (Figure 96) shows little urban development. Unfortunately, images for the years between 1955 and 1975 are unavailable. Demographics included in the 1966 Local Urban Plan show that there was a 66% increment in the population of Orvieto Scalo from 1955 to 1964 (Figure 114). This population growth was reflected also on an important development in the built environment, as shown by the number of rooms built in Orvieto Scalo from 1951 to 1961, the locality that changed the most (Figure 114). The 1975 orthophoto (Figure 97) shows both the development already present by 1964, as well as an increase in the built area in correspondence to the reinforcement of existing activities in Orvieto Scalo, as proposed in Piccinato's 1966 Plan.

Figure 107 shows how the locality of Ciconia was consolidated by 1975 and continued to grow in 1980, following what was proposed in the 1966 Plan, to create a "real" urban area at the left bank of the Paglia River. Indeed, Piccinato's plan was responsible for the development of this locality. It is very important to note that Arch. Piccinato was aware of the possibility of flooding from both the Paglia and

Chiani Rivers. He was reassured by the Civil Engineers Department, which had taken some structural measures upstream to protect both the Chiani and Paglia banks, in the sectors where development was foreseen. It is important also to state that the 1966 Plan foresaw in these zones a green area with parks where later, during the '80s, an industrial area was developed.

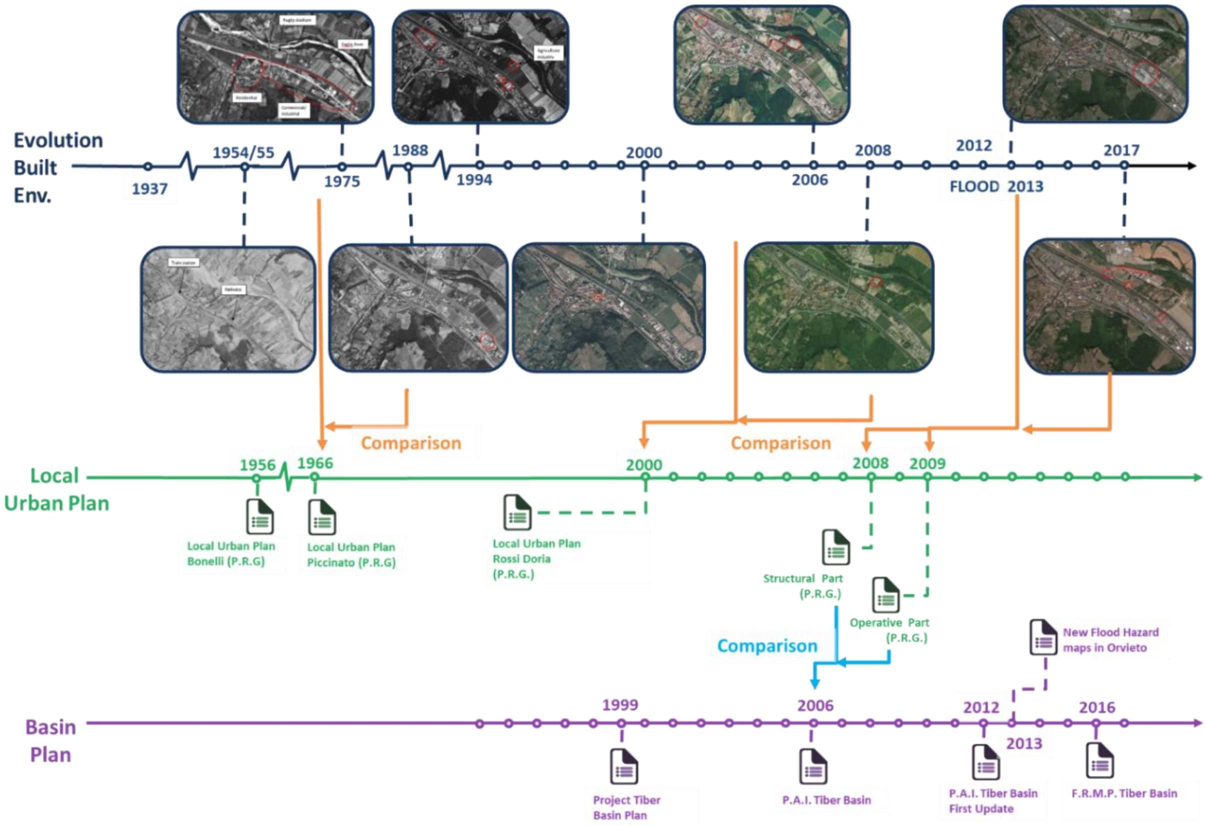


Figure 122 Orvieto Scalo Case Study, Investigation of the role of spatial planning in shaping disaster risk, Comparisons (source: author).

New residences in Ciconia at the banks of the tributary of the Paglia River fall inside band B of the P.A.I., which means that they should not have been built without mitigation measures. They were erected before 2006, while the P.A.I. was under approval. However, even if the P.A.I. had been enforced, hazard maps did not include flooding from this tributary, which has been included for the first time in the 2013 update of the maps (Figure 66).

Most important changes in Ciconia from the adoption of the 2008 (Structural Part) and 2009 (Operational Part) Urban Plan occurred in the industrial area. New structures with parking lots were built at the bank of the Paglia, as foreseen in the Plan. These new buildings are outside the flood-prone area as defined by the maps of the P.A.I. 2006 and First Update 2008 (Figure 65). This means that the Technical Norms from the P.A.I did not apply. The updated version of the flood hazard maps of 2013 (Figure 66) includes some of these new industrial buildings and private parking lots in band C (floods of extreme intensity, with very low frequency), a zone with no constraints to new development, except for linear infrastructure. A big new private parking space is located instead in band A, in the 2013 version of the hazard map. Unfortunately, this parking lot was already built by that time.

Table 50 Results of Comparisons of Analyses in Orvieto Scalo and Ciconia (source: author).

Questions	**Locality**
	Orvieto Scalo and Ciconia
Were changes in the built environment foreseen in local urban plans?	Yes.
Do Local Urban Plans comply with the norms of the Basin Plans?	Yes. However, hazard maps were updated after the local plan was enforced, making some land uses defined in the local plan incompatible with the norms in the basin plan.
Has urban development complied with Basin Plans?	Yes. Tributaries were not mapped when development took place in band B in Ciconia. Development in Ciconia and Orvieto Scalo took place before and while the hazard maps were updated.

An important change in Orvieto Scalo after the adoption of the 2008/2009 Urban Plan occurred between 2012 and 2013, with the construction of a new shopping mall. This Plan foresaw a commercial area in what was by then a free lot. The Technical Norms of the P.A.I. of 2006 were not applied in Orvieto Scalo because the flood hazard map did not indicate this area as flood prone, except for a small, already built portion (Figure 65). A new version of the map was available in 2013, after the important flood of 2012, which flooded all Orvieto Scalo and showed the limitations of this map. Thus, even if the flood hazard was known, the new shopping mall was erected because it was already under development and officially the norms did not apply.

6.4 SECTION II.B: RISK REDUCTION AND PREPAREDNESS

In the Chiani River, there were dykes in place in 2012 that provided some protection to Ponticelli. The 2015 Flood Risk Management Plan foresees the construction of measures with high priority to protect Ponticelli. They consist of new levees and the restoration of the riverbed and channels.

There were no hydraulic works in place in 2012 that protected Orvieto Scalo and Ciconia. The 2012 flood incentivized the planning of hydraulic works in the Paglia River, funded by the Umbria Region. These flood protection measures were included in the F.R.M.P. in 2015, according to which these measures are under construction, some of them inaugurated in May 2017. They consist of 7 different projects that create a levee at both sides of the Paglia River, in correspondence to Orvieto Scalo and Ciconia. These structural measures were given high priority in the F.R.M.P., motivated by the 2012 flood.

Regarding other types of prevention measures, the data collected by the Polimi group after the 2012 flood shows that affected economic activities in Orvieto Scalo did not take any prevention measures.

6.5 SECTION III: WHAT HAPPENED?

6.5.1 Flood protection infrastructure performance

The levees in place in the Chiani River that provided some protection to Ponticelli broke during the 2012 flood. In fact, the levees broke in three different places, which resulted in the flooding of Ponticelli.

6.5.2 Damages and impacts on economic activities

The analysis of the damages in the case study of the Umbria Region focuses on damages to economic activities, which is a choice motivated by (i) the availability of damage data and (ii) the possibility of exploring another damaged sector in opposition to the Grimma case study.

The analysis focuses on the localities of Orvieto Scalo and Ciconia, where more detailed data were collected by both the authorities and the Polimi group. The municipality of Orvieto distributed a form for affected enterprises that was associated to the Decree of August 9th, 2013, n.3 "Provisions for the granting of subsidies to non-agricultural enterprises damaged by the flood events referred to in the Decree of the President of the Council of Ministers on 23 March 2013". There were many requirements that the affected enterprises needed to fulfil for accessing compensation, like the impossibility to close their activity for the following 5 years. These requirements in some cases could not be satisfied by the damaged activities and so not all of them presented a request to the municipality.

The considered types of enterprises are the non-agricultural and defined in the form as "industry", "tourism", "handicraft", "commerce" and "service". Data collected by means of the forms were complemented by data from the decision included in the decrees DFR 24/12/2013 and DFR 19/02/2015, which provide a list of admissible compensation requests and the amount of money they received.

It is important to note that the data collection was performed at the municipal level, without a distinction of the location of the affected activity in terms of locality. Intensive work was required to classify the damaged activities by locality and, in some cases, this was not possible. The next analysis is based on this classification. There are 15 damaged activities that could not be localized within the Orvieto municipality.

6.5.2.1 Orvieto Scalo

It was possible to locate a total of 77 damaged activities in Orvieto Scalo. The damages in monetary values associated with these activities are reported in Table 51, classified between damages to the building, the equipment and raw materials and goods. The total damages amount to around €21.8 Million.

Table 51 Damages to enterprises in Orvieto Scalo (source: author).

Orvieto Scalo	**Damage in [€]**
Damage to buildings	€ 3,482,343
Damage to equipment	€ 7,957,519
Damage to raw materials and goods	€ 10,366,645
Total	€ 21,806,506

Figure 123 shows the distribution of damaged activities by type (i.e. commercial, handicraft, handicraft/commercial, gas station, industrial, restaurant, service, touristic). These typologies are more refined with respect to the ones present in the forms to distinguish the restaurants and bars from touristic activities and other services, and the gas stations. Gas stations when flooded can cause water pollution. Most of the damaged enterprises are commercial (32%), followed by handicraft (26%) and Services (10%).

Some of the damaged activities are both commercial and handicraft (7%). Damaged touristic activities and industrial activities represent 8% each.

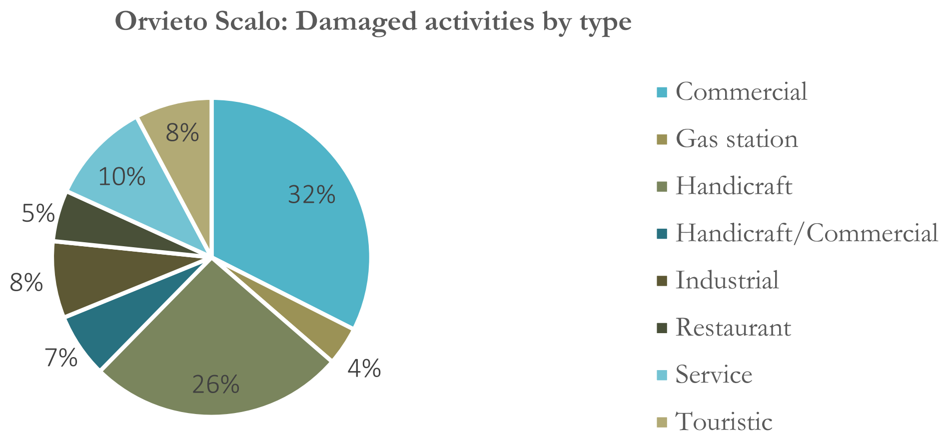


Figure 123 Damaged activities by type in Orvieto Scalo (source: author).

Damages to Building, Equipment, and Materials and goods

Damages to the building (structure and fixed installations), to equipment (machinery, vehicles, furniture) and raw materials and goods (finished product, stock, raw materials) are expressed in monetary values. These damages are analysed by type of activity. Figure 124 shows that most of the total damages were sustained by commercial activities. The handicraft and the mixed handicraft/commercial follow but with much fewer damages. This result is in line with Figure 123, where the most numerous damaged activities correspond to these categories.

The commercial activities suffered damages mostly to goods, which is expected because these are the goods that they sell and have in stock. Instead, handicraft activities suffered the most damages to equipment. For all the activities, the damages to the buildings are the smallest ones in monetary terms.

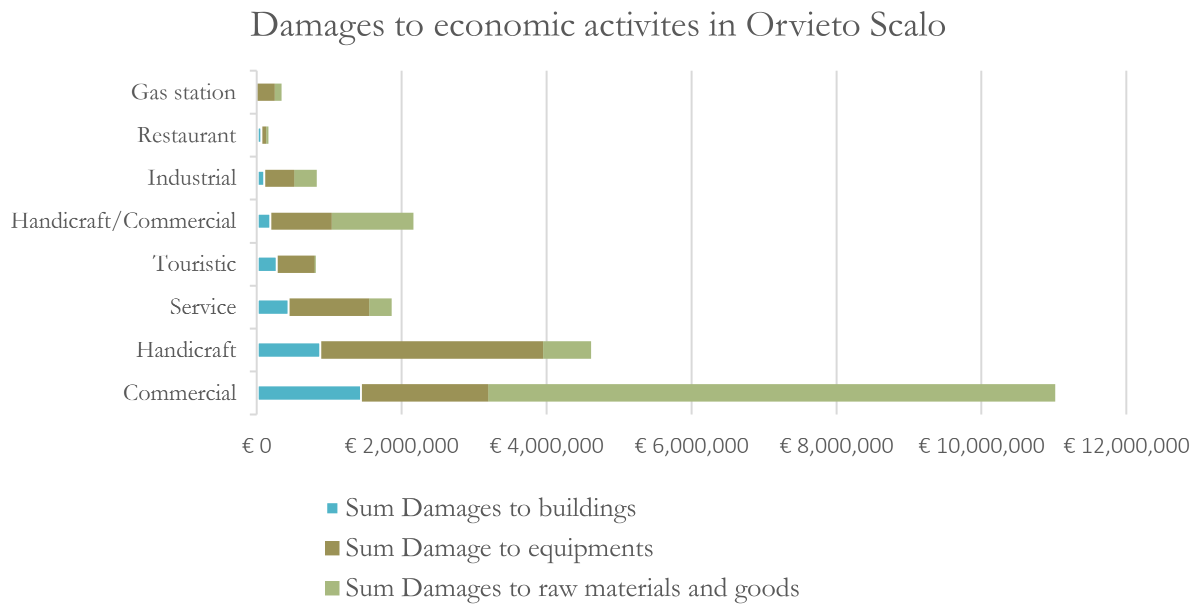


Figure 124 Damages by type and activity in Orvieto Scalo (source: author).

Insured and uninsured damages

Data on insured and uninsured enterprises against floods were collected in the forms distributed by Orvieto Municipality. Given that some forms were missing and that some affected companies did not make compensation requests to the government, this information is not complete. It is important also to note that it is possible that insured companies did not present the requests for public compensation, therefore, this analysis represents partially the reality. Figure 125 shows that only approximately € 2.5 Million damages were insured, of a total of € 21.8 Million (12%).

It is important to note that there are only data on insured and uninsured companies of a subset of 28 enterprises from a total of 77 damaged activities in Orvieto Scalo. The insured damages represent 25% of the total damages of the subset of 28 enterprises. Insured enterprises amount to only three, two of which are commercial and one service company (Figure 126). The uninsured enterprises cover a variety of activity types.

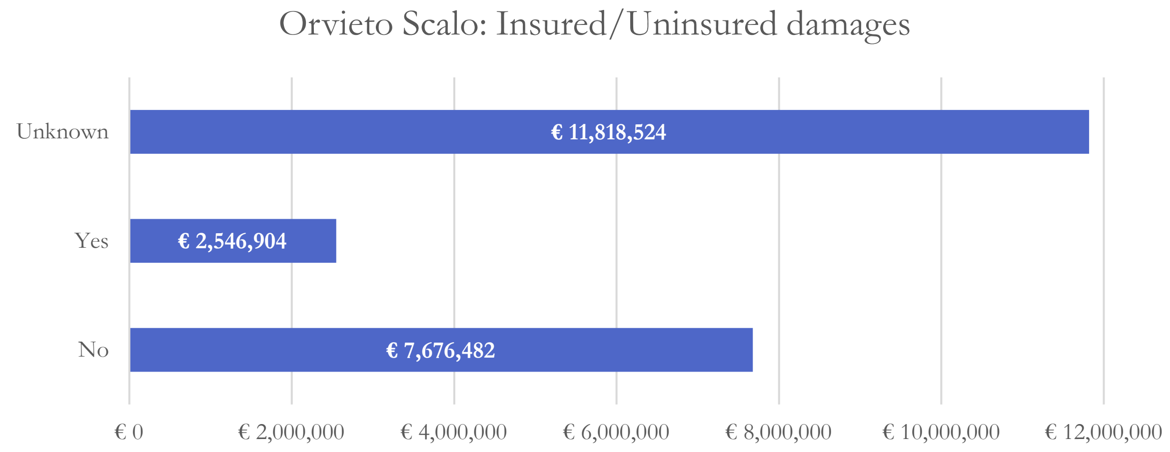


Figure 125 Insured and uninsured damages of economic activities in Orvieto Scalo (source author).

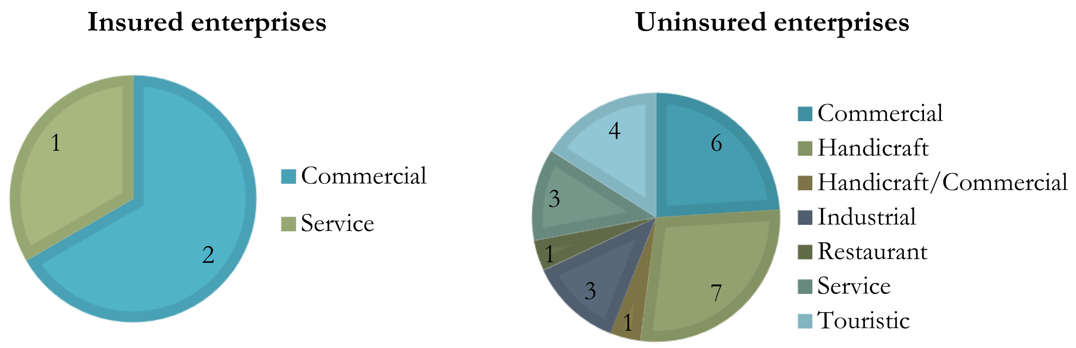


Figure 126 Insured and uninsured damaged enterprises in Orvieto Scalo by type of activity (source: author).

Indirect impacts

The form set by the Orvieto municipality collected also data on the date in which activities were resumed in the affected companies. The number of days of inactivity provide an idea of the indirect impacts, understood in these case as a proxy for the lost revenue, given that they are days were no added value is produced. However, the forms had to be presented in the municipality within a month from the flood. Most of the affected companies presented the form within 2 and 3 weeks of the flood, while their activities were still interrupted. The surveys done by the Polimi group in November 2012 show the same picture: all the activities had been closed for 15 days. The only business that fully restarted their activities was the gas station, after 14 days of closure.

6.5.2.2 Ciconia

A total of only 11 damaged activities were located in Ciconia. The damages in monetary values associated with these activities are reported in Table 52, classified between damages to the building, the equipment and raw materials and goods. The total damages amount to around to around € 900.000.

Table 52 Damages to enterprises in Ciconia (source: author).

Ciconia	**Damage in [€]**
Damage to buildings	€ 281,900
Damage to equipment	€ 243,424
Damage to raw materials and goods	€ 396,000
Total	€ 921,324

Figure 127 shows the distribution of damaged activities by type (i.e. commercial, handicraft, handicraft/commercial, gas station, industrial, restaurant, service, touristic). Most of the damaged activities comprise service (55%) and commercial (18%) companies.

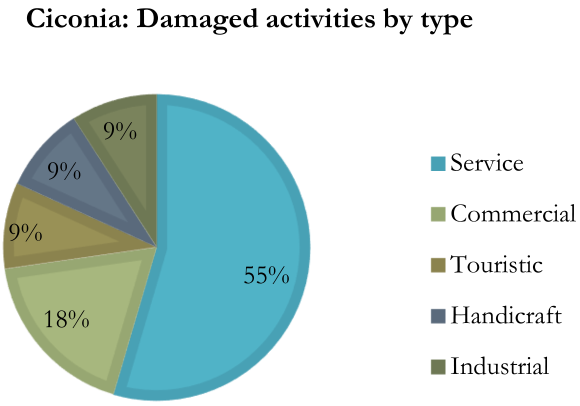


Figure 127 Damaged activities by type in Ciconia (source: author).

Damages to Building, Equipment, and Materials and goods

Damages to the building (structure and fixed installations), to equipment (machinery, vehicles, furniture) and raw materials and goods (finished product, stock, raw materials) are expressed in monetary values and analysed by type of activity.

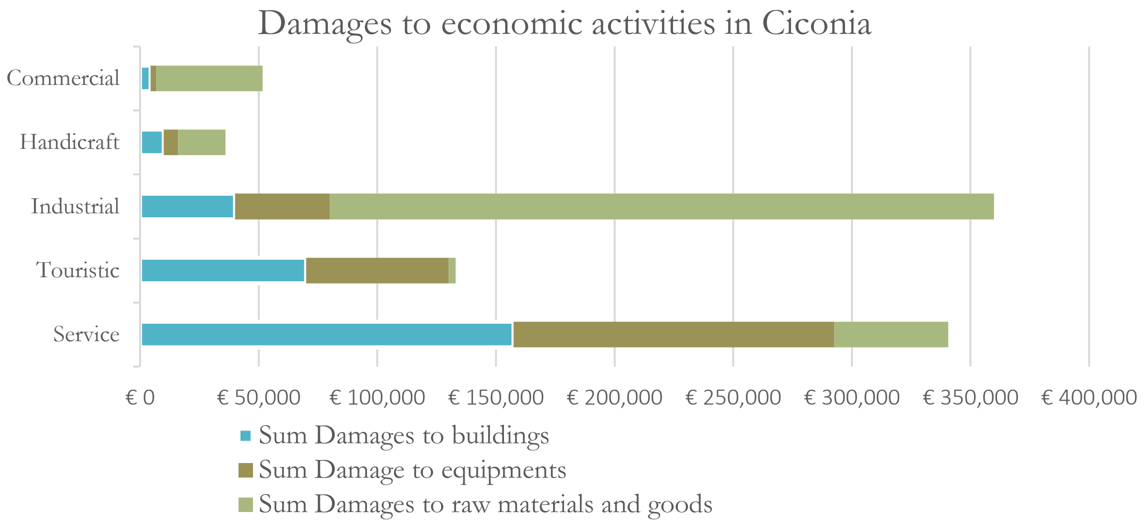


Figure 128 Damages by type and activity in Ciconia (source: author).

Figure 128 shows that the industrial sector sustained the biggest amount of total damages, followed by the service sector. However, all the industrial damage corresponds to just one company (Electrolink), as shown in Figure 127, and mostly involves damage to raw materials and goods. This company belongs to the broadcasting technology sector (Figure 129), where the products are costly, which explains the large number of damages to the stock of finished products and materials (€ 280.000). Instead, both the service and touristic sectors suffered more damages to the buildings than to the other categories.

It is important to note that the two damaged businesses shown in Figure 129 are outside the flooded area of 2012, as reconstructed and shown in Section I. Moreover, the building hosting the car rental is always located outside the flood-prone areas as defined in all the basin plans because it is elevated with respect to its surroundings. Nevertheless, this building was damaged during the flood.

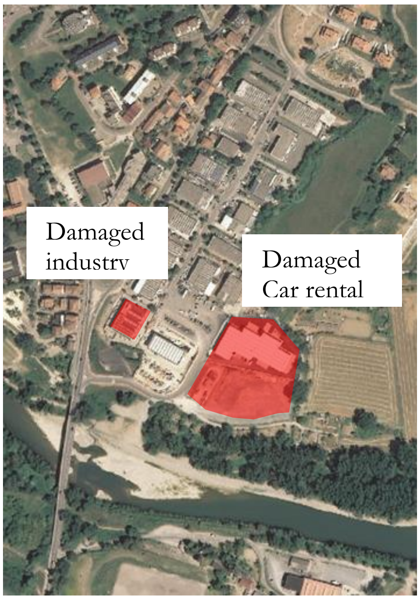


Figure 129 Some damaged economic activities in Ciconia 2012 (source: google maps).

Data on insured and uninsured enterprises against floods were collected in the forms distributed by Orvieto Municipality. Given that access to these forms was partial, the availability of insurance of most of the enterprises and their associated damages are unknown and they were not analysed for Ciconia. Indirect impacts suffer from the same data incompleteness and, thus, their analysis was not possible either.

6.5.3 Response of damaged economic activities

In Orvieto Scalo, the surveyed companies took no emergency measures because they were not alerted in the days immediately prior to the event nor did they consider the alert that was given by the Civil Defense on the media as having immediate repercussions (Ballio et al., 2013). Moreover, the Adunata bridge (only one at that time connecting Ciconia and Orvieto Scalo) was closed at 5.30 am on November 12th (2 hours before flooding) so the employees and the owners could not arrive at their workplace to take any measures. In the case of the Orvieto Scalo Alfa Romeo dealer, most of the cars could have been saved by placing them on the roof of the building if the employees had had time to take measures. In other cases, the peak of the flood arrived fast and they had no time. There is no information regarding the response of activities in Ciconia.

6.5.4 Recovery of damaged economic activities

In order to understand the recovery of the damaged enterprises, the amount of compensation provided by the Regional government was analysed. Table 53 shows the mean ratio of the public compensation received by each company to the total damages they reported for both Orvieto Scalo and Ciconia. Even if the data set corresponding to Ciconia is small, the results show similar values with respect to Orvieto Scalo, where a bigger sample is available. This means that the compensation received by the damaged enterprises was around 25 - 30% of the total damage they suffered (as reported).

In addition, strong requirements were set for enterprises for accessing to compensation, limiting the accessibility to some affected businesses. At the same time, public compensation did not require the adoption of measures to reduce the vulnerability of damaged businesses during reconstruction.

Table 53 Mean ratio of compensation to total damage of enterprises in Orvieto Scalo and Ciconia (source: author).

Locality	**Mean ratio of compensation to total damage**
Orvieto Scalo	0.29
Ciconia	0.26

The surveys done one year after the flood by the Polimi show that 2 weeks after the flood the affected companies at most restarted activities at 50% with respect to the values before the flood. Activities resumed at full regime between the end of February and the beginning of March 2013 (Ballio et al., 2013).

6.6 SECTION IV: LESSONS LEARNED

6.6.1 Flood hazard maps

The forensic investigation in Orvieto Scalo and Ciconia revealed the shortcomings of existent hazard maps. In fact, the flood hazard map in Orvieto Scalo was “corrected” after the 2012 flood. A similar situation regards the industrial area in Ciconia. Two of the damaged businesses are outside the reconstructed flooded area of 2012 and the flood-prone areas in hazard maps. The maps in Ciconia are still the same. Flood hazard maps could also be improved if after floods the damaged objects are mapped, as in this case.

6.6.2 Spatial planning role in shaping Disaster Risk

In all the three cases (Ponticelli, Orvieto Scalo and Ciconia) flood hazard maps with related norms were enforced "too late", when major urban development had already taken place or was in progress. In Ponticelli, spatial planning played no role in either limiting or preventing disaster risk. The analysis of the evolution of the built environment shows that flood exposure always increased and consequently did flood risk. If the rate of growth of flood exposure decreased, it was only because of a lack of interest in investing in the area and not because of spatial planning. However, a positive aspect to note in Ponticelli is the transformation of some vacant areas from industrial to agriculture in 2016 in the structural part of the urban plan. These areas were defined as industrial in the year 2000 and ratified in the 2011 plan. The 2012 flood probably had a positive effect in raising awareness, which was translated into the urban plan.

Regarding the restrictions associated with the flood hazard maps, the case of Ponticelli is even worse because there were no hazard maps until 2012. These norms and restrictions were not applied retroactively and so operational plans already in place were not affected. These include still unbuilt areas that were destined for commercial and industrial activities in the 2002 Plan of Public initiative, located in band A of P.A.I. and P1 of the F.R.M.P (the zone with the highest probability of flooding). The same situation regards the other two industrial areas in the north and the south of the provincial road. When the lots will be assigned and built, flood exposure and risk will increase again.

In Orvieto Scalo and Ciconia, flood awareness dates from 1966 with Arch. Piccinato's plan. He was aware of the possibility of floods from the Paglia River and he even mentions important floods like the one of 1937. He considered flood risk in the urban plan because he destined the area immediately next to the river to green spaces (i.e. public parks, sports fields, playgrounds and walkways). However, Piccinato's successors seem to have forgotten about flood hazard. In Ciconia, they transformed the green areas to industrial. This zone was developed during the '80s giving rise to numerous industries and shops (some of which were flooded in 2012). In Orvieto Scalo, they changed agricultural land next to the river to industrial, and collective services to industrial and commercial, all of which were flooded in 2012.

A year after the 2012 flood, a new shopping mall was inaugurated in Orvieto Scalo. This shopping mall was under construction when the flood hit and was foreseen in the 2008/2009 urban plan (it was a vacant lot by then). Again, Piccinato's successors forgot about historic floods that inundated that area. The Technical Norms of the P.A.I. of 2006 were not applied because the flood hazard map did not indicate this area as flood prone. The new version of the map was enforced in 2013 after the flood revealed that this area was wrongly marked. However, this was again too late because the lot was under development. It seems that no measures were taken to reduce the vulnerability of the shopping mall nor its parking lot either.

6.6.3 Prospective and Corrective risk reduction

Flood protection infrastructure did not perform well in Ponticelli, where three failures in the levees led to flooding. New structural measures are under development in the three localities analysed, given high priority. Concerning other possible prevention measures, in Orvieto Scalo economic activities did not take any measures to prevent damages to their businesses.

6.6.4 Flood damages

The different types of economic activities suffered different damages, both in value and in type. The commercial activities suffered damages mostly to the goods that they sell and have in stock. In contrast, handicraft activities suffered the most damages to equipment.

In Ciconia, the industrial sector sustained the biggest amount of total damages, where all the damage corresponds to just one technology company and mostly consists of damage to raw materials and goods. Instead, both the service and touristic sectors suffered more damages to the buildings than to the other categories.

Besides, the flooding of the gas station and the paint shop in Orvieto Scalo resulted in the scatter of both fuel and paint in the flooded area. This shows that commercial activities vary also with respect to the indirect damages they can cause, as in the case of pollution of flood water that can affect both the environment and human health.

6.6.5 Response and Recovery

Economic activities in Orvieto Scalo did not take any measures during the response phase because of different reasons. In some cases, they were not alerted in the days prior to the event. In others, they ignored the alert broadcasted by the media. Last, they realised too late and did not have time to take measures.

Additionally, there was no reconstruction planning nor incentives for affected enterprises to take measures to lower their vulnerability. Public compensation did not require the adoption of measures to reduce the vulnerability of damaged businesses during reconstruction, so there was no build back better.

The recovery of damaged companies took several months. Available data indicate that most of the companies were not insured against floods and needed to turn to public compensation. However, the compensation they received amounted to only one-fourth of the direct damages that they suffered. The total damage that businesses suffered was even greater. Compensated damages do not consider indirect damages that result for example from the lost revenue in the days of inactivity.

7 DISASTER FORENSIC INVESTIGATION FOR SPATIAL PLANNING

This chapter starts with the presentation of the "Revised" New Method for Disaster Forensic Investigation in the first section. It continues in the second section with the definition of the data categories that are required for the application of the new method for Disaster Forensic Investigation. This section also presents the assessment of the fitness of the post-flood damage data collection process for disaster forensic investigation in the Grimma and Umbria case studies.

The third section presents the lessons learned from Disaster Forensic Investigation and their use in spatial planning. Both case studies are analysed in terms of their lessons learned and their contribution to the DRR knowledge base in spatial planning. The fourth section discusses the possible planning levels where this new DRR knowledge can be introduced. It starts by showing the potential introduction of the lessons learned and actions from the case studies in existing planning instruments in Italy, France and Germany. Next, Disaster Forensic Investigation is linked to actions and measures to mainstream flood risk prevention and reduction in spatial planning. A new taxonomy of flood risk prevention and reduction measures is developed that, in association to the lessons learned from Disaster Forensic Investigation, supports the selection of actions to effectively mainstream flood risk management in spatial planning at different levels. The chapter concludes with a reflection on possible organisations that could be in charge of performing the Disaster Forensic Investigation in Italy, France and a more general scenario applicable to other countries.

7.1 REVISED NEW METHOD FOR DISASTER FORENSIC INVESTIGATION

The Disaster Forensic Investigation method developed in this research is a comprehensive analysis that extracts lessons learned regarding the causes of the disaster and its damages and the role of spatial planning in shaping risk (both negative, as a risk driver, and positive by preventing risk). The development of this new Disaster Forensic Investigation method was an iterative process. The method (as developed in Chapter 4) was applied to both case studies (Grimma and Umbria). Then, the method was improved during its application to the case studies, culminating in the proposal of a revised method for Disaster Forensic Investigation. This revised method was developed with Prof. Scira Menoni. It represents the way forward for better future forensic investigations.

The structure of the "old" method, as defined in Chapter 4 and used in the analyses of the case studies, is useful to organise and clearly present the results of the Disaster Forensic Investigation. In fact, the case study analyses, as presented in Chapter 5 for Grimma and Chapter 6 for Umbria, follow a temporal logic. It starts from the pre-event phase, goes through the emergency phase and finishes with the recovery and reconstruction phase. As we have seen, these phases include the study of different factors (e.g. the hazard characteristics, the mitigation measures taken pre-event, the damages, the recovery process, etc.), which are organised in sections. This structure presents to the reader a clear "story" of what happened before, during and after the disaster. Nevertheless, this structure is not very effective for supporting the analyst that performs the Disaster Forensic Investigation. In fact, it does not help in identifying the connections between the different factors that may have contributed to the gestation of the disaster and to its damages. Besides, all these factors are described in separate sections, but they require to be connected in order to allow the extraction of the lessons learned. For example, the characteristics of the hazard event are analysed in Section I, whereas the exposure and vulnerability of the built environment are included in Section II and the disaster damages and impacts are presented in Section III. It is necessary to relate the hazard event with the exposure and the vulnerability of the built environment in order to explain the damages sustained.

This "revised" new method consists in an improved framework that:

- Establishes all the factors that require analysis in a forensic investigation.
- Defines the interactions between the different factors that explain damage causality.
- Analyses the causal chain between the "more immediate" factors (e.g. hazard, exposure, vulnerability, etc.), the risk drivers and the more profound root causes.
- Guarantees that all the different types of damages that can result from a hazard event are analysed, including not only physical damage but also the loss of function of different interconnected systems (systemic damage) and long-term impacts.
- Ensures that all the causal factors that are relevant in explaining each type of damage are investigated. It acts as guidance, indicating the factors that require investigation in each type of damage scenario.

- Allows visualising the interactions between the different factors to facilitate the extraction of the lessons learned.

Figure 131 shows the framework of the revised new method for Disaster Forensic Investigation (Mendoza & Menoni, 2019). It indicates in the first column the root causes, in the second column the risk drivers, moving to the right it depicts the factors to be analysed and last, the different damage scenarios. The horizontal array represents the causal chain, with arrows that indicate the relationship between the root causes that give rise to the risk drivers, and between the risk drivers and the factors that result from them. These factors consist of the physical damage reduction, the emergency response, the recovery and reconstruction process, the exposure, the hazard, the physical and the systemic vulnerability and the resilience. These factors interact during the disaster, giving rise to the different damage scenarios (i.e. physical damage, systemic damage, and long-term damage scenarios). The interactions among these factors, and between these factors and the damage scenarios are indicated with different arrows. The vertical arrows indicate the connections between the damage scenarios, representing that one type of damage can lead to another (e.g. the physical damage of a lifeline may cause the interruption of its functioning and even the outage of another lifeline, that is systemic damage). The root causes and risk drivers indicated in Figure 130 constitute some examples.

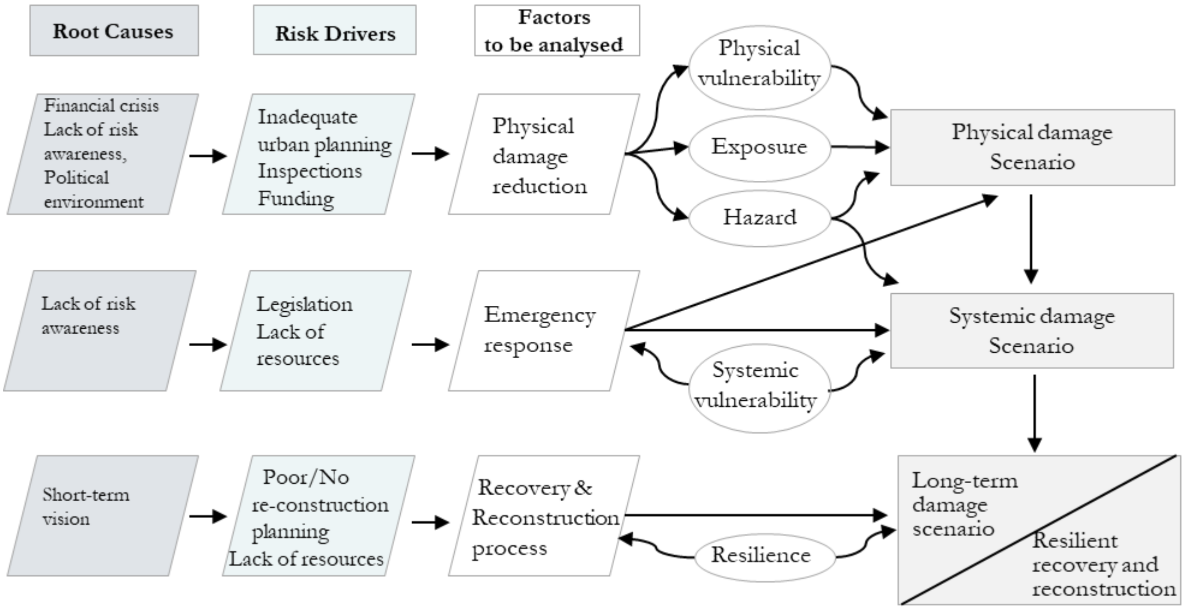


Figure 130 Framework of the revised new method for Disaster Forensic Investigation (source: Mendoza & Menoni).

Concerning the factors to be analysed, the physical damage reduction comprises the actions taken pre-event towards the reduction of either the physical vulnerability, the exposure or the hazard factors. The emergency response and the recovery and reconstruction process indicate the actions that were taken during the unfolding of the disaster, in the emergency phase and the recovery phase, respectively. The emergency response is conditioned by the systemic vulnerability, which represents the susceptibility of different systems to suffering disruptions. A similar situation regards the resilience factor and the recovery and reconstruction process. This process is strongly dependent not only on the actions taken during the recovery period but on how resilient the social and economic systems are. The arrows indicate the interactions between all these factors but also the influence of a factor in the unfolding of a specific damage scenario. Therefore, these factors need to be investigated in relation to that damage scenario.

For the physical damage scenario, the factors to be analysed are the hazard, the physical vulnerability and the exposure of people, the built environment and the economic assets, in conjunction to the efforts towards the reduction of physical damages. These are different kinds of measures that were taken before the unfolding of the event, and that act on either the hazard, the vulnerability and/or the exposure. Moreover, in order to fully understand the unfolding of the physical damage scenario, it is necessary to consider also the emergency response. Some measures taken during the emergency phase can have a positive effect on preventing physical damages, for instance through civil protection activities to save lives or through individual measures to avoid damages to households. The emergency response can also have a negative impact and contribute to the aggravation of physical damages.

The unfolding of the systemic damage (or loss of function) scenario is conditioned by several factors, including the physical damage scenario. This is particularly important for networks and systems of different kinds. For instance, a damaged pylon of a power network can cause a service disruption at a large scale. The emergency response can also affect the systemic damage scenario, where actions taken during the emergency phase can be key to guarantee the functioning of many systems. As mentioned, the systemic vulnerability of the built environment, of the social and of the economic systems, is another very important contributing factor to both the emergency response and the systemic damage scenario. The systemic vulnerability of the built environment in the form of networks' interdependency is a crucial feature that explains the loss of function in many undamaged systems. For instance, the lack of functioning of the power system can put many other systems at risk of disruption, such as the telecom, water or even the economic system. It is also worth mentioning the possibility of the hazard directly affecting the functioning of a system or a critical facility. This would be the case of flooded, yet physically undamaged, infrastructure that temporally loses function, or the case of a flooded or inaccessible police station that interrupts its activities.

The long-term damage scenario is influenced by the systemic damage scenario, the recovery and reconstruction process and the resilience of the social and economic systems. If the loss of function of systems has a long duration, then the long-term damages can increase, as in the case of companies that cannot return to business when the power or the mobility systems do not work. This is also true when the economic or social systems are not very resilient, making the recovery process slow, while long-term damages rise.

Moving one link back in the causal chain, we go from the factors to the risk drivers. So far, the attention has been set to the investigation of spatial planning as a risk driver, due to either inadequate planning or a lack of planning at all. This is true also for reconstruction planning, where a lack of planning can hamper the process. There are other risk drivers that can also emerge from the disaster forensic investigation. For example, inadequate or out of date legislation, lack of funding, resources, poor controls or inspections, etc.

Moving yet another link in the causal chain, we arrive at the root causes. Identifying the root causes is not an easy task, and either is the linkage of these root causes to the risk drivers. These root causes explain why the risk drivers exist in the first place. For example, having a short-term vision (root cause) may determine the lack of planning for a possible reconstruction (risk driver) during the pre-event phase or even afterwards, during the recovery period. Likewise, a lack of risk awareness (root cause) may determine a lack of allocation of resources for emergency planning (risk driver) or inadequate urban planning (risk driver), without any DRR considerations. Connecting risk drivers to root causes permits to identify if and where it is possible to act to break the causal chain. As mentioned in Chapter 3 in the description of the FORIN approach, some relations between risk drivers and root causes could be avoided, where others are inevitable, associated with the development paradigm.

In connection with the development of this revised new method, Figure 131 shows the links between the structure of the "old" method (as described in Chapter 4 and used in the case study analyses) and the new one. As mentioned, the different factors that require analysis in the forensic investigation were treated in separate sections in the previous method. Figure 131 specifies the section in which each factor and risk driver was analysed. The analysis of each factor as defined in the "old" method is maintained for the new method. For example, the hazard factor was studied in Section I. This section analysed different aspects of the hazard, considering not only the specific flood event that affected the area under study but also the general hazardousness of the area. This last aspect includes the analysis of historic floods. All of these analyses are necessary and must be executed as defined in Chapter 4 and as shown in the case studies of Grimma and Umbria.

Another example is the analysis of spatial planning as a potential risk driver, using the "method to Investigate Spatial Planning role in shaping Disaster Risk", developed in Chapter 4 and applied in the Umbria case study. Results of the application of the method were included in Section II.A of the "old method" and help to "fill in" the risk drivers' box in the framework of the new method. Figure 131 shows as an example of a risk driver inadequate urban planning; this risk driver would be identified through the application of the method to Investigate Spatial Planning role in shaping Disaster Risk. The exposure and vulnerability of the built environment were also analysed within the application of that method.

A similar situation regards the physical, systemic and long-term damage scenarios, as well as the emergency response and recovery process. They were all addressed in Section III of the previous method, in the "What happened" section.

To conclude, an applied scheme of this framework can present and summarise the lessons learned from Disaster Forensic Investigation. This scheme is applied to both the Grimma and the Umbria case studies to show and summarise the lessons learned extracted in Chapter 5 and 6, respectively. These schemes could be added to the last section of the Disaster Forensic Investigation, where the lessons learned are presented (Section IV).

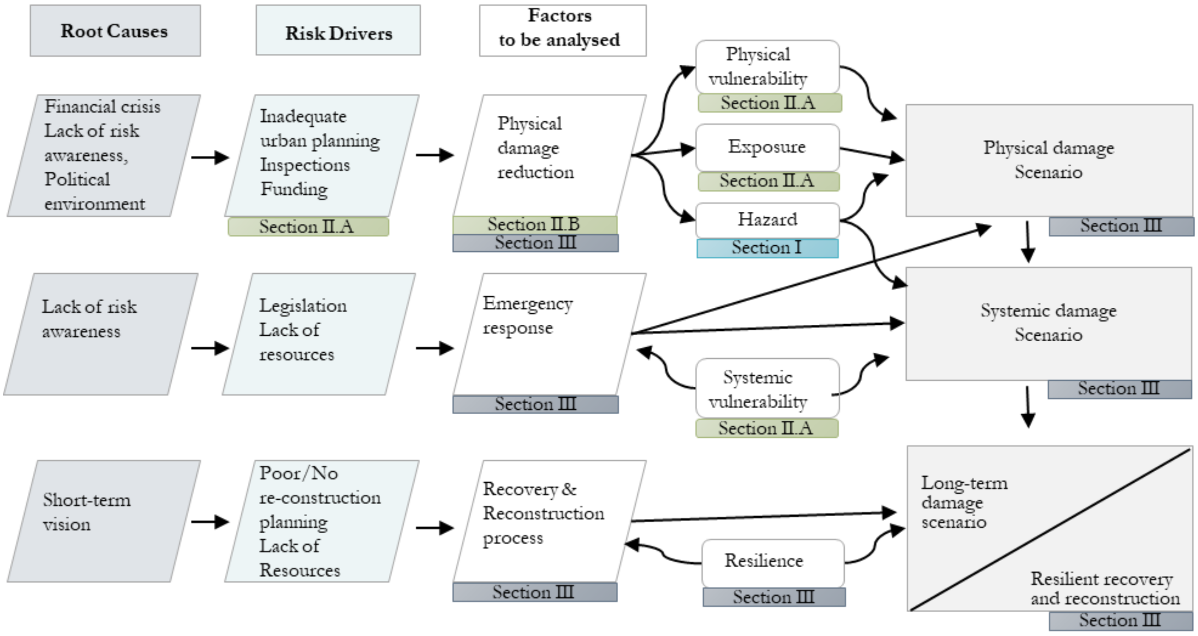


Figure 131 Links between the framework of the new method and the "old" one (source: author).

Figure 132 shows the applied scheme of the framework to the Disaster Forensic Investigation for the 2013 flood in Grimma. It is possible to visualise the connections between the root causes, the risk drivers, the factors and the damage scenarios. For example, it is possible to see how the inadequate planning of the flood wall, with a design that was insensitive to its context and to the citizens' needs, is a risk driver, partially motivated by policies that did not call for a participatory approach (the Floods Directive was not enforced at that time). Then, there were no measures in place for flood protection during the 2013 flood (given that the problem with the citizens delayed the construction) and so another "flood of the century" happened, only 11 years after the previous one. There were, however, measures for physical damage reduction at the household level. On the other hand, measures taken by household residents during the emergency response also contributed to the mitigation of some physical damages.

Evacuation in Grimma in 2013 was ineffective even if flood warning was effective thanks to the new early warning system set after the 2002 flood. This was probably motivated by the lack of risk awareness of residents that were unwilling to evacuate and possibly by insufficient resources. Moreover, all the roads in the city centre were submerged and unusable during both floods, making the centre inaccessible, including the police headquarters that were isolated and flooded in 2013. All the commercial and touristic activities were interrupted. In fact, there was a drop in tourism after the 2013 flood.

The recovery and reconstruction process after the 2013 flood were affected by the low economic resilience of businesses, which did not have insurance nor the capacity to increase their debt, as they were already paying for the loans from the 2002 flood. Moreover, the lack of public financial resources in 2013 also affected the process. It is unclear if the reconstruction of the city centre considered the reduction of the vulnerability of the buildings. There was no reconstruction planning, and this aspect was left to the discretion of each owner and was not very promoted by the government.

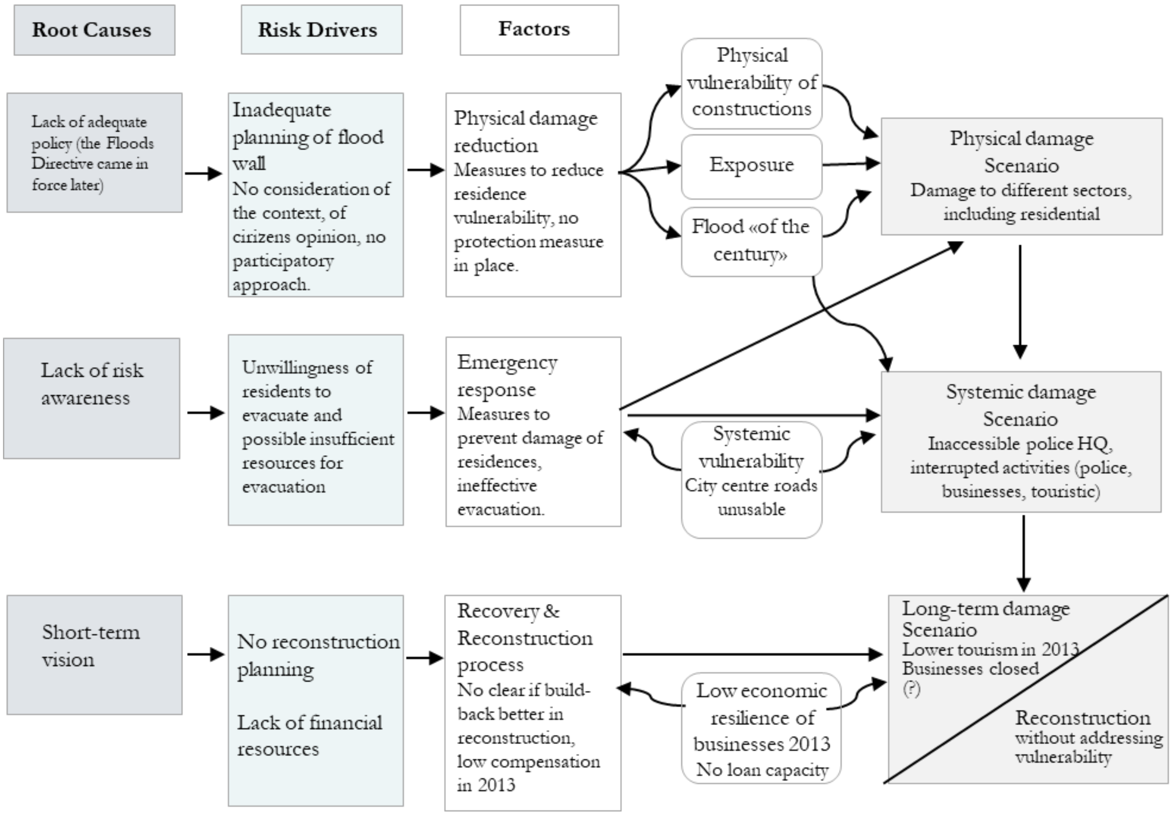


Figure 132 Lessons learned of the Disaster Forensic Investigation of the 2013 flood in the Grimma case study (source: author).

Figure 133 shows the applied scheme of the framework to the Disaster Forensic Investigation for the Umbria case study. It shows as the main risk driver the inadequate spatial planning, with no consideration of flood risk, combined with the late enforcement of constraints to development in flood-prone areas. This risk driver gave rise to an increase in the exposure of the built environment, with vulnerable constructions. No measures were taken before the flood towards physical damage reduction on any of the factors (i.e. exposure, vulnerability and hazard).

Businesses suffered physical damages to their buildings, equipment and goods, and the distribution of these damages depend on the type of economic activity. No measures were taken by business owners to mitigate damages during the emergency response because they either ignored the flood alert given in the media or they received it too late and did not have time to arrive before the closure of the only bridge that provided access. Therefore, the physical damages to businesses were very important and caused the interruption of their activities.

Regarding the long-term damage scenario, most of the affected businesses required months to return to their previous level of operations, if this was even possible. Some businesses could not benefit from governmental compensation and most of them were uninsured, which slowed down the recovery process. There was no reconstruction planning and access to public compensation did not require the adoption of measures to reduce the vulnerability of damaged businesses. Therefore, there was no build back better during reconstruction.

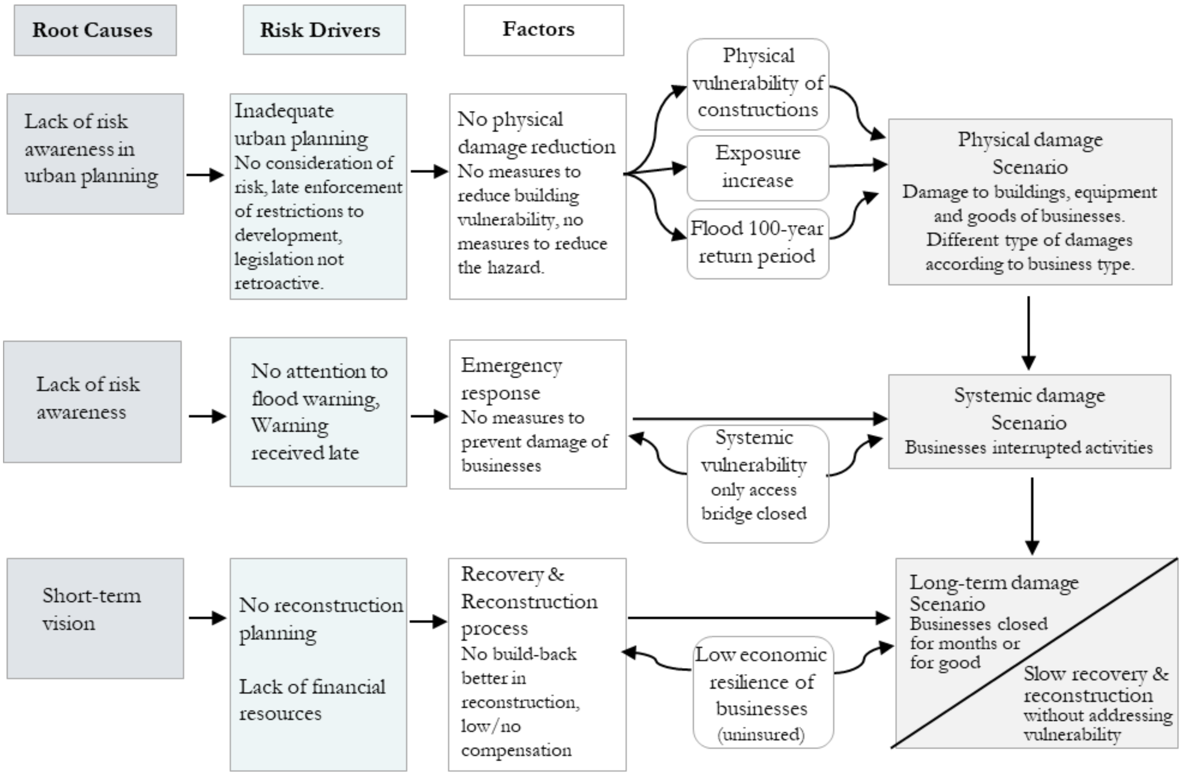


Figure 133 Lessons learned of the Disaster Forensic Investigation of the 2012 flood in the Umbria case study (source: author).

7.2 POST-FLOOD DAMAGE DATA COLLECTION FOR FORENSIC INVESTIGATION

To be able to apply fully the new Disaster Forensic Investigation method, all the necessary data categories must be collected. Therefore, it was decided to define all the data categories that are required to support the application of the new method. This section also presents the assessment of the fitness of the post-flood damage data collection process for disaster forensic investigation. The characteristics of damage data can affect the analysis and the applicability of the disaster forensic investigation. It is therefore important to assess if these data, which are produced through a specific assessment and collection process, are suitable for a disaster forensic investigation and to identify their possible shortcomings. The assessment of the fitness of the post-flood damage data collection process for forensic investigation is done through the evaluation of the quality of the collected data, as defined in Chapter 4, for both the Grimma and Umbria case studies.

7.2.1 Data categories for Disaster Forensic Investigation

The policy review on disaster damage data collection in chapter 3 reveals that there are three main data categories that are required to be collected after a flood event to perform a disaster forensic investigation and other types of analyses. These categories are (i) Hazard event data, (ii) Damaged object data and (iii) Damage data. Yet, the literature review on disaster forensic approaches in chapter 3 and the application of the forensic methods in the case studies show that these three data categories are not enough for a disaster forensic investigation. In order to understand the causes of the disaster and its damages, it is necessary to investigate different aspects of a disaster. For doing so, more data categories are necessary.

In consequence, a new framework of data categories for disaster forensic investigation is proposed that includes not only data that are collected post-flood event but also all other necessary data categories that refer also to the pre-event. Categories of data collected post-event comprise also "Response data" and "Recovery data". Data categories that refer to the pre-event include "Prevention measures data", "Hazard data", "Exposure data", "Vulnerability data", "Risk data" and "Contextual data". Table 54 lists all these data categories and provides some examples.

Table 54 Data categories for Disaster Forensic Investigation (source: author).

Data categories for forensic investigation	**Data examples**
Hazard event data	Flood return period, water depth, flooded area.
Damage data	Physical damage to the building, disruption of service, number of deaths.
Damaged object data	Presence of basement in a damaged building, the location of the damaged school, type of damaged road.
Response data	Type of emergency measures taken, warning time.
Recovery data	Number of re-built buildings, financial aid per household.
Prevention measures data	Type of measures taken during the prevention phase, number of prevention measures per household.
Hazard data	Flood-prone area for different return periods, water depth per flood scenario, water velocity per flood scenario.
Exposure data	Number of residents in the flood-prone area, number of schools in the flood-prone area, infrastructure in the flood-prone area.
Vulnerability data	Land-use in a flood-prone area, critical services in the flood-prone area.
Risk data	Expected damage for flood scenario.
Contextual data	Total population, population age structure, GDP.

The "Hazard event data" category refers to the data related to the characteristics of the hazard of the disaster under investigation. For a flood, these would be the characteristics of the flood that occurred, such as the return period and the flood extent. The "Damage data" category includes data on the different damages and impacts associated with the disaster or flood event (e.g. physical damage to infrastructure, power outage, etc.). The "Damaged object data" comprises data on the characteristics of the objects damaged by the flood, for instance, the location of a damaged building or the age of a damaged bridge. The "Response data" category includes data related to the response activities, namely activities performed during the emergency period, such as the emergency measures taken at the household level. The category on "Recovery data" refers to data on the recovery and reconstruction phase, for instance on the availability of funds or the reconstructed infrastructure. The category "Prevention measures data" is self-explanatory, comprising all the data related to the measures taken during the prevention phase to mitigate flood risk (before flood occurrence).

The “Hazard data” category must not be confused with the “Hazard event data” category. “Hazard data” refers to data on potential flood events, i.e. flood scenarios that can materialize in the study area. These flood scenarios are usually associated with a probability of occurrence, expressed as a return period, and represented as hazard maps containing data on the flood extent and sometimes on water depth and velocity. The “Exposure data” category refers to data on the exposed elements, i.e. elements located inside the flood-prone areas. Of course, these elements are associated with a flood scenario, which defines the “flood-prone area”. The exposed elements differ from the damaged objects because they are objects that could be potentially damaged if a particular flood occurred.

The “Vulnerability data” category refers to data on the vulnerability of the exposed objects. The “Risk data” category comprises data on the flood risk under which the study area is. The risk is intended as a function of hazard, exposure and vulnerability, and may be represented as a map portraying the expected damage for a given flood scenario. Last, the “Contextual data” category comprises all the other data that do not fall in the previous categories and provide information on the disaster’s context. For instance, this category includes data on the demography, economic data (e.g. Gross Domestic Product and unemployment rate), base maps, etc.

The timing of the collection of the defined data categories varies. Some of these data can be collected during the post-event, such as the Hazard event data, the Damage data or the Damaged object data, whereas the Contextual data are generally historical data, collected periodically regardless of the disaster event. The next sections explore the data categories collected through the post-flood damage data collection processes in the Grimma and Umbria case studies, as well as the assessment of their fitness for disaster forensic investigation.

7.2.2 Grimma case study: Post-flood damage data collection for forensic investigation

The post-flood damage data collection process related to the residential sector is assessed in the Grimma case study. This data collection process is associated with the HOWAS21 database, introduced in the review on selected European databases in Chapter 3. These data are collected through computer-aided telephone interviews with affected residents, as explained in detail in Chapter 4. These data include different categories in accordance with the categories defined in the previous section for data required for forensic investigation. The collected data on the residential sector comprises the following categories:

- Hazard event data
- Damage data
- Damaged object data
- Response data
- Recovery data
- Prevention measures data

As we can see, even if the data collection process occurs post-event, the collected data does not only cover the collection of data on the disaster itself (i.e. Damage data, Damaged object data, Hazard event data and Response data) but also includes data that describes the pre-event phase, such as data on prevention measures. The timing of the data collection determines the possibility of collecting data about the post-event state, e.g. data on the recovery phase. In both flood events, the data collection was performed around 8 and 9 months after the flood events and, thus, it was possible to collect data on the recovery process.

All the collected data are incomplete for disaster forensic investigation. Only "affected residents" were interviewed. This means that only households that suffered monetary flood damage are considered within the sample. Consequently, data was not collected for households that, though being in the flooded area, had not suffered any monetary damage. This has many consequences. First, the data set partially covers the flooded area and the amount of data on the hazard event (i.e. flood duration, water depth and presence of contaminants) are not enough for a forensic investigation because they do not constitute a representative sample of the hazard characteristics. Second, it is not possible to aggregate the data to provide an overall picture of the damage at a different spatial level, for instance at a town or municipal level. Last, data on flooded but undamaged buildings would be useful for comparing with households that did suffer damages and for individuating the factors that were drivers of these damages. Multiple reasons could explain why damages were not sustained, among them both measures taken during both the prevention and emergency phases. These data could highlight the effectiveness of implemented measures.

Concerning the free-of-error dimension, the evaluation is negative for the data on damages to building and contents because the household residents assess the damages in a non-systematic way, which could mean that data are not reliable either because some damaged items are not considered, or because the monetary value does not include all the damages sustained. Data mostly have a consistent representation. However, there is no consistent representation from one flood event to the other because some interview questions were changed from 2002 to 2013. This affected, for instance, the type of prevention and emergency measures considered and the type of damaged contents.

Concerning data usefulness, the amount of data on damages to buildings is considered as appropriate for forensic investigation, even if the number of damaged households is small. Buildings are quite homogeneous in the inner city of Grimma, suggesting that the sample is representative of all the damaged buildings. If building typologies had been very different, a bigger sample would have been necessary to ensure that it represented the high variability of the resulting damages. In contrast, the amount of data on damages to contents is assessed as not appropriate for forensic investigation because residential contents are generally very variable from one household to another.

Data objectivity is problematic regarding the monetary values of both the damages to the building and contents, as well as financial aid. These data are provided by the affected residents themselves and they constitute a sensitive issue that could make people underestimate or overestimate values. Moreover, the data concerning the physical damages to both the buildings and contents in monetary values are assessed as not interpretable because they lack clear definitions of what they represent. These monetary values could represent different things. Physical damages to both building and contents can be expressed as costs of replacement or repair, depending on whether the damaged item or part 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. This issue was partially solved by adding a question on the damage estimation method, available only for the 2013 flood.

The characteristics of the hazard event of 2013 revealed further criticalities. Being an event with two phases, it is not well represented by data of different types. For example, flood duration data do not reflect the fact that the 2013 flood event consisted of two phases and are, thus, incorrect. Likewise, warning time for residents could involve errors because it is not clear if it refers to the time before the first flooding phase or if it refers to the second phase of the flood event.

Data usability is mainly governed by data accessibility. Accessibility to data stored in HOWAS21 depends on the type of user, while the user group "world" can only use predefined analysis. However, these data can be accessible under request and in certain cases.

Consistency in data representation is a problem particularly for the data collected for the 2002 flood event. These data were collected through computer-aided telephone interviews, which means that many different persons conducted the interviews and inserted the data, each with a different format. This was solved in the 2013 data because the fields for inserting the data were changed ensuring that the data was inserted in the same format every time.

Regarding the specific use of the data in a forensic comparative analysis (where at least two events are necessary), the sampling methods used to select residents to make the interviews varied with one event to the other, making the samples less comparable. For the 2013 flood, a larger sample was collected, where all the retrieved telephone numbers were contacted. These data do not contain all the damaged households, but only those households that were listed in the official telephone registry. Nowadays, mobile phones are replacing landline phones, especially between young generations, and given that the official telephone registry contains only landline telephone numbers, not all the residents are listed. Moreover, changes in the interview questions make comparability difficult as well.

Besides data quality, another important aspect regards the fact that data collection and recording are not systematically done. The HOWAS21 database relies on voluntary data contributions, which sometimes means that data on some flood events are either not collected or not recorded in the database. This is the case of the data on damages to the residential and commercial sectors of the 2013 floods in

Germany, still not recorded in HOWAS21 due to restrictions in data ownership (reportedly, they will become available soon).

7.2.3 Umbria case study: Post-flood damage data collection for forensic investigation

The post-event data collection in the Umbria case study considerably differs with respect to Grimma. At the time of the 2012 flood there were no established procedures for post-flood damage data collection and either for data recording in an organised way (i.e. in a database). Instead, thanks to the work by the Politecnico di Milano and the Civil Protection of the Umbria Region, these procedures were developed during the emergency and in the immediate post-event. The procedure developed for post-flood data collection is called RISPOSTA (Reliable InStruments for POST event damage Assessment) and covers the damage data collection for both the residential and industrial/commercial sectors.

The RISPOSTA procedure has been perfected since its application in the 2012 flood and re-tested during a second flood event that hit the same region in 2013. Initially, the data was collected with paper forms. Later, a software application was created to support the data collection process and to allow the direct recording of these data in a database. This database was designed during the IDEA project, in which this research is embedded. Additional efforts are still required to continue with the design and modelling of this database to permit the recording of the damage data of all possible damaged sectors, and that supports multiple purposes, including forensic investigation. The review in Chapter 3 shows that there are currently many efforts in place in this direction.

With respect to RISPOSTA, what is in contrast with the data collection process of the Grimma case is that it consists of direct surveys in the field, executed by trained surveyors. Therefore, the quality of the data collected is also different, as it will be shown next. The collected data comprises different categories, as defined in the previous section:

- Hazard event data
- Damage data
- Damaged object data
- Response data
- Prevention measures data

The collected data comprise not only data on the disaster (i.e. data on the hazard event, the damages, the damaged object and the response) but also on the measures taken pre-event (prevention measures data). The timing of the data collection determines the possibility of collecting data on long-term damages. In fact, the RISPOSTA procedure considers this aspect and so the damage data in the Umbria case were collected in two occasions following the 2012 flood, which permitted to assess the long-term damages of the industrial and commercial activities.

Data on the hazard event, such as the water depth, were collected through direct measurement of the marks left by floodwaters by trained surveyors, both outside and inside each building level. Moreover, they are all referred to the street level. All these aspects make these data virtually "free-of-error".

Similar considerations regard the physical damages to the building and its contents. The data was collected just a few days after the flood event. Therefore, the surveyors were able to directly assess the damages to the buildings and contents, such as damages to the walls, the installations, furniture, appliances, etc. This ensures the reliability of the data.

In general, data have a consistent representation. This is true even if the data were collected through the paper forms. It is important to note that data are ensured a consistent representation since the development of both the data collection interface and the database.

Concerning data usefulness, data objectivity is problematic regarding the monetary values of both the damages to the building and contents. These aspects cannot be directly assessed by the surveyor and are provided by the affected residents, which could underestimate or overestimate values. Data on monetary damages are considered interpretable because the values were generally described in detail in the "notes" section. This aspect has been improved during the IDEA project by allowing the differentiation between repair and replacement costs and by indicating the assessment method.

7.3 LESSONS LEARNED FROM DISASTER FORENSIC INVESTIGATION FOR SPATIAL PLANNING

The lessons learned from Disaster Forensic Investigation constitute DRR knowledge that can enrich the current knowledge base used in Spatial Planning at different levels. This DRR knowledge then supports the definition of different types of actions to both prevent and reduce disaster risk through spatial planning.

The way in which these actions can be mainstreamed in spatial planning at different levels is through two approaches. The first one concerns the introduction of DRR measures in spatial planning. These measures, as currently defined in DRR, can be integrated inside planning instruments. The second approach consists of spatial planning as a DRR measure itself. In this case, spatial plans are itself instruments for risk prevention and reduction.

At the same time, these actions can address (i) the existent built environment and "as is" situation, (ii) the future built environment or (iii) the existent or future built environment in other similar areas. Actions on the existent built environment comprise measures that modify the existent built environment and the present situation. Actions on the future built environment include measures that mostly influence new development, but also how the existent built environment will be redeveloped in the future. Actions in similar areas consist of measures either for the existent built environment or the future one, but in zones that have similarities with the investigated area.

As mentioned, the aim of these actions is risk prevention and reduction. Risk prevention means avoiding the generation of new disaster risk, in order to avoid potential damages of hazardous events. Risk prevention actions address new development, either by completely avoiding their location in hazardous areas or by limiting their exposure and vulnerability. In contrast, risk reduction focuses on the mitigation of existing disaster risk, i.e. addressing the existent built environment and related activities. It is important to mention that in DRR, measures can also be classified with respect to the phase of the disaster management cycle in which they are being implemented (see for example Table 2 in paragraph 2.2). In this case, "prevention measures" would refer to measures taken during the prevention phase, that is the period of time before the disaster occurs. It is important not to confuse these two definitions. The "prevention measures" that refer to the ones taken during the prevention phase, in fact, comprise measures for both risk prevention and reduction, as previously defined here.

Figure 134 shows how the lessons learned extracted in the Disaster Forensic Investigation can be used for the mainstreaming of risk prevention and reduction in spatial planning. The figure indicates that these lessons learned are used to improve the DRR knowledge base in spatial planning at different levels. This DRR knowledge base is then used to define different actions. These actions are first classified according to where they act, i.e. the existent built environment and «as is» situation, the future built environment and the existent or future built environment in other similar areas. The second categorisation distinguishes between the introduction of DRR measures in spatial planning and the use of spatial planning as DRR measure by itself. A further and last distinction is made according to the aim of the action, i.e. risk prevention or risk reduction.

Table 55 presents examples of each category of actions. The actions based on the DRR knowledge that act on the existent built environment and «as is» situation in spatial plans comprise "DRR measures in Spatial Planning for risk reduction" and "Spatial Planning as DRR measure for risk reduction". The first category refers to the introduction of DRR measures to reduce existing risk inside spatial plans, like the introduction of mandatory flood insurance frameworks or programs for the construction of flood protection infrastructure. The second category refers to spatial plans that act as risk reduction instruments, as in the case of the relocation of some constructions from hazardous areas.

The actions on the future built environment include different categories. First, "Spatial Planning as DRR measure for risk prevention" indicates the use of spatial planning for prevention for the future built environment. For instance, by defining land-uses for new areas that are compatible with the level of hazardousness. Second, "Spatial Planning as DRR measure for risk reduction" consists of spatial planning as a measure for reducing risk through redevelopment. The redevelopment of the existent built environment is an opportunity for flood risk reduction that must not be wasted. For example, through the set of building regulations for floodproofing, raising buildings or differentiated uses by floor for redevelopment. Last, "DRR measures in Spatial Planning for risk prevention" include measures from DRR used for risk prevention, such as building regulations to floodproof new constructions.

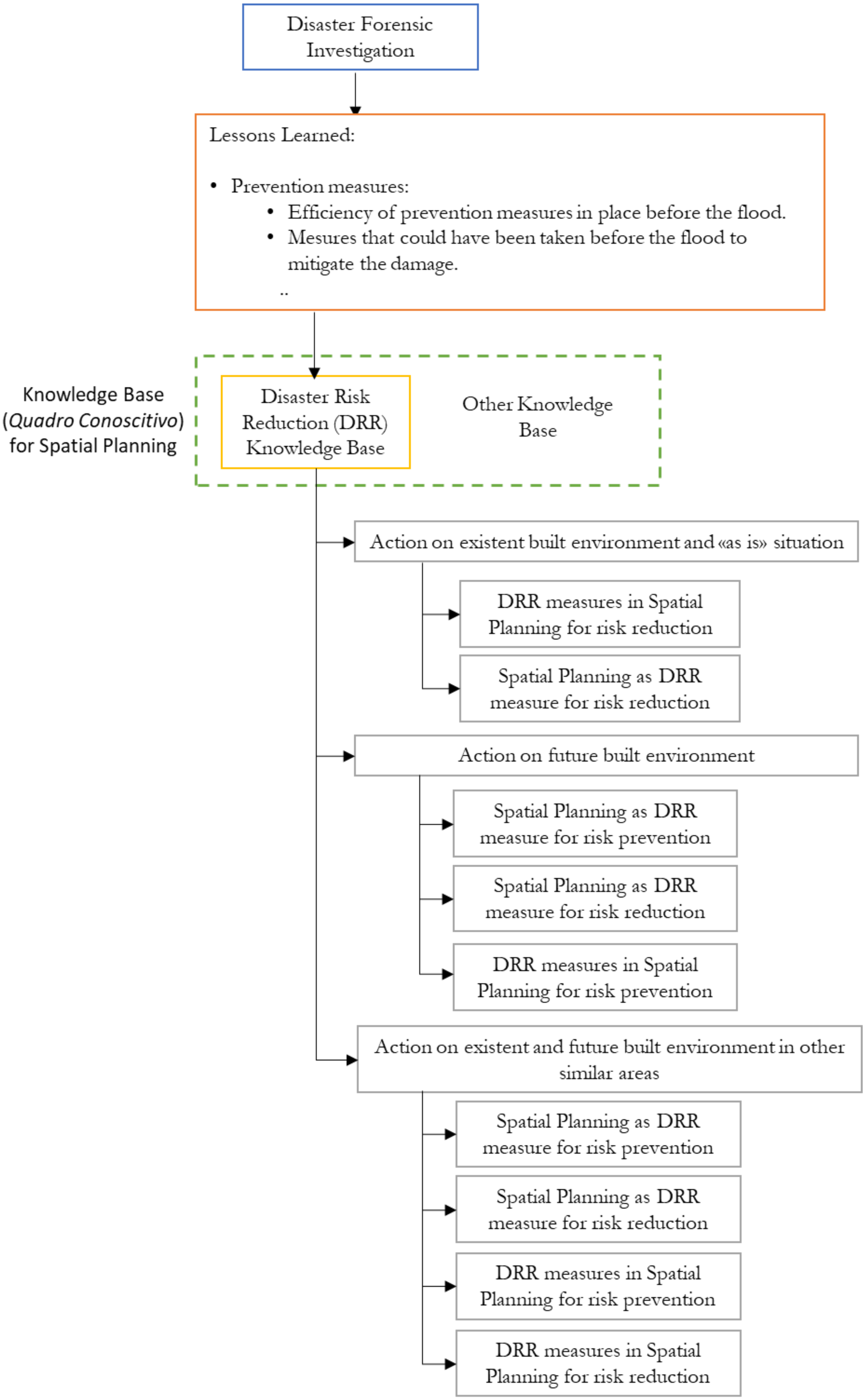


Figure 134 Lessons learned from Disaster Forensic Investigation for the knowledge base for spatial planning (source: author).

Table 55 Examples of actions in spatial planning for risk prevention and reduction (source: author).

Actions	Types of measures	Examples
Action in the existent built environment and "as is" situation	DRR measures in Spatial Planning for risk reduction	Hydraulic invariance principle for existing constructions
		Mandatory flood insurance frameworks in flood-prone areas
		Programs for the construction of infrastructure for flood lamination
		Renaturalisation of floodplains
		Integrated management of floodplains
	Spatial Planning as DRR measure for risk reduction	Regulations for flood-proofing existent buildings and infrastructure, including raising buildings
		Relocation from hazardous areas
		Change of use of lower levels of buildings
		Verification and redefinition of urban planning for residential and/or industrial areas along the river
		Land-use transformations in favour of the ones with lower vulnerability
Action on the future built environment	DRR measures in Spatial Planning for risk prevention	Regulation such as the hydraulic invariance principle for new constructions and redevelopment
		Integrated management of floodplains
	Spatial Planning as DRR measure for risk prevention	Retention areas and environmental protection designations
		Building regulations (floodproofing) for new constructions
		Regulations for floodproofing new public buildings and infrastructure
		Land use planning avoiding flood-prone areas, prohibition to build in flood-prone areas
		Spatial planning that outlines land uses compatible with the hazardousness of the territory
		Location of public buildings and infrastructure in safe(r) areas
		Use in buildings distinguished by level
		Raising buildings
		Prohibition to build underground levels
	Spatial Planning as DRR measure for risk reduction	Building regulations (floodproofing) for redevelopment
		Regulations for floodproofing public buildings and infrastructure for redevelopment
		Spatial planning that outlines land uses compatible with the hazardousness of the territory
		Use in buildings distinguished by level for redevelopment
		Raising buildings for redevelopment
		Prohibition to build underground levels for redevelopment

Actions	Types of measures	Examples
Action on existent and future built environment in similar areas	DRR measures in Spatial Planning for risk prevention	Same measures as in the previous categories
	DRR measures in Spatial Planning for risk reduction	
	Spatial Planning as DRR measure for risk prevention	
	Spatial Planning as DRR measure for risk reduction	

The actions on both the existent and the future built environment in other similar areas refer to actions for territories that have comparable characteristics to the area analysed in the Disaster Forensic Investigation. The lessons learned support the definition in similar areas of: "Spatial Planning as DRR measure for risk prevention", "Spatial Planning as DRR measure for risk reduction", "DRR measures in Spatial Planning for risk prevention" and "DRR measures in Spatial Planning for risk reduction". These lessons learned generally contain knowledge on the effectivity of the prevention measures in place before the flood and on the measures that could have been taken before the flood to mitigate the damage. These two kinds of results are particularly useful to learn for other similar situations.

Next, I will present the lessons learned from each case study (Grimma and Umbria), as DRR knowledge to enrich the knowledge base used in spatial planning. I present also examples of the different actions that can be defined from these lessons learned and mainstreamed in spatial planning in each case study, as well as the actions for similar areas.

7.3.1 Grimma case study: Lessons learned for spatial planning

The lessons learned in the Grimma case study comprise several aspects, one of which is the efficiency of measures in place before the floods. This case study is very interesting because the analysis of the two consecutive floods permitted also to comprehend if measures taken after the first flood (2002) were effective during the second one (2013). This was only possible thanks to the comparison of the different aspects of both disasters.

The Disaster Forensic Investigation revealed that the measures taken during the prevention phase and during the emergency at the household level were effective in mitigating the physical damages of the floods. Moreover, the new early warning system installed after the 2002 flood proved to work well in warning the population in the 2013 flood.

Another interesting lesson learned arises from considering what could have been done before the flood that would have prevented some damages and impacts. In the Grimma case study, a participatory approach for planning and, most importantly, for designing the flood wall would have accelerated the construction process. This process started after the first flood and was delayed due to the opposition of the residents that were unhappy with the way the levee was designed. The 2013 flood occurred while the wall was still under construction and did not provide any protection. In fact, the Floods Directive requests participatory approaches, whereas some politicians after the 2013 flood in Saxony and the issue with the flood wall were inclined to avoid these approaches in the future.

Additional lessons learned include the discovery that floods have an impact on population dynamics that can be negative or positive. In fact, this is another interesting aspect of the case study that reflects the complexity of urban disasters, where two events can cause different impacts in the same place when happening at different moments in time. The city centre became more attractive due to the refurbishment after the 2002 flood, which attracted a new population. This was also associated with the availability of public financial aid and the positive publicity that the town had in both national and international media. The 2013 flood had the opposite effect, causing emigration from the city centre. This is explained by the lack of public financial aid, the negative attitude of both the population and mayor and the negative public image in the media.

One more lesson learned is the businesses' lack of capacity to obtain financial loans after the 2013 flood. It was conditioned by the previous flood that compelled some businesses to get loans. This situation, combined with scarce public funds, undoubtedly hampered the recovery of affected businesses in 2013.

In addition, the new police headquarters, built after the first flood, was flooded during 2013 and isolated. Accessibility roads were completely submerged, certainly impeding the normal functioning of the police headquarters.

Figure 135 synthesises the lessons learned from the application of the Disaster Forensic Investigation in the Grimma case study. It shows that these lessons are added to the DRR knowledge base in spatial planning. Different types of actions are proposed for Grimma and other similar areas based on this DRR knowledge.

The next actions are proposed for future spatial plans in Grimma. These actions address the existent built environment and "as is" situation and the future built environment. Moreover, other actions are proposed for the existent and future built environment that are useful for other similar areas.

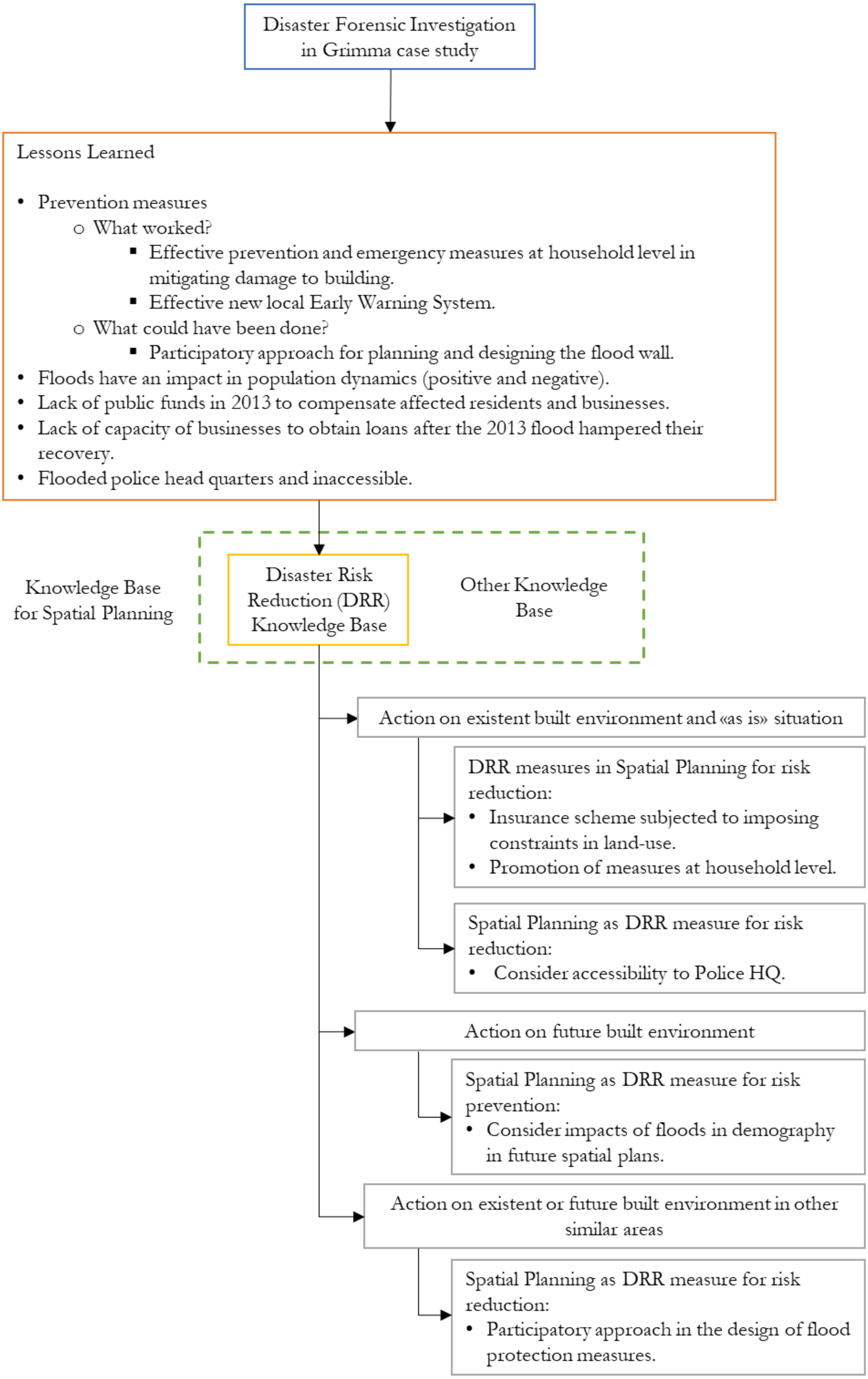


Figure 135 Lessons learned in Grimma case study and proposed actions by category (source: author).

The proposed actions on the existent built environment and «as is» situation aim at risk reduction, through DRR measures in Spatial planning and Spatial planning as a DRR measure. The DRR measures in spatial planning for risk reduction include setting an insurance scheme at the state level and promoting its penetration subjected to imposing constraints to floodplain development at the municipal level. Existing flood insurance schemes lack this important aspect. Constraints to development in floodplains must accompany this flood insurance scheme in order to avoid the generation of more flood exposure and risk. This should consider also the land behind dykes, which is still under flood risk and highly susceptible to suffering the "levee effect", where development is encouraged by a false sense of safety. It would be a scheme like the National Flood Insurance Program in the United States of America. A higher penetration of flood insurance would have helped the affected residents and businesses in recovering after the second flood in 2013. It would still be useful for future floods, even after the flood wall is finished, given that it provides a certain level of protection (100-year return period), which would be overcome by more severe floods.

Another possible DRR measure to introduce in spatial plans includes the promotion of measures to reduce the physical vulnerability of buildings, as one of the lessons learned showed their effectivity in preventing damages in 2013. Last, another measure that can be taken for risk reduction on the existing situation is to consider ways to guarantee the accessibility to and from the police headquarters in future spatial plans in Grimma.

Actions on the future built environment focus on risk prevention. In the development of future spatial plans, it is necessary to consider the impacts that future floods may have in demographic trends. Future floods could alter the scenarios envisaged in the plans and even threaten them with a possible depopulation.

Last, action on the existent or future built environment in other similar areas consider the use of participatory approaches in the design of flood protection measures, and more generally, for setting flood risk management plans. Moreover, structural measures like this one, defined at basin level, should also be coordinated and integrated into spatial plans at lower levels.

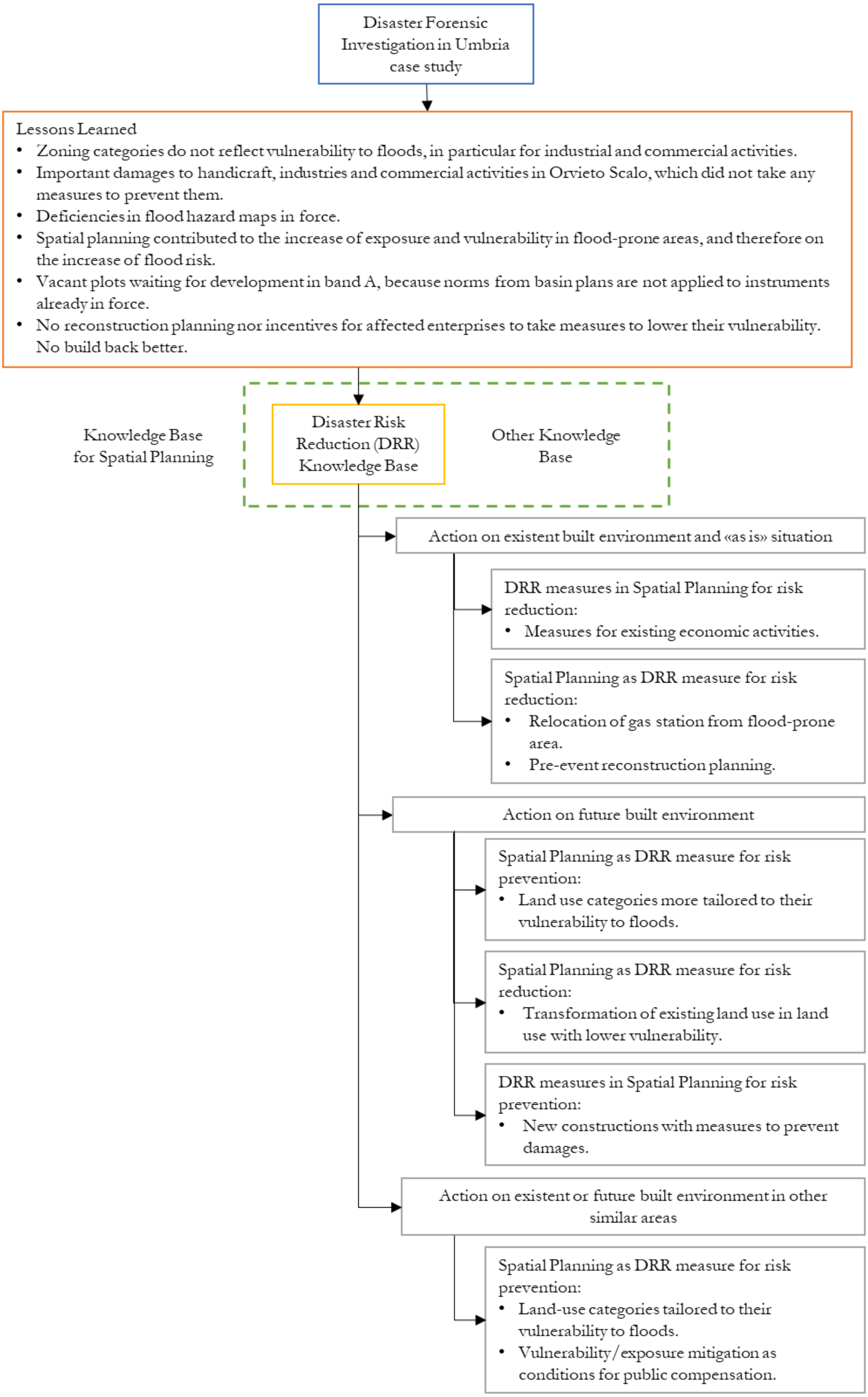
7.3.2 Umbria case study: Lessons learned for spatial planning

The lessons learned in the Umbria case study concern several aspects, starting from the fact that current zoning categories in local plans do not reflect flood vulnerability. The disaster forensic investigation shows that different types of businesses suffered different damages, both in monetary terms and in type (i.e. damage to the building, equipment and goods). The land use classified as "industrial" ("insediamenti produttivi") in Orvieto comprises uses that have different vulnerabilities, which translate after a flood in different amounts of damages. It is possible to see from the difference in "industrial" companies in Orvieto Scalo and Ciconia that their physical damages can be very different according to the products they manufacture. It is also true that in both Ciconia and Orvieto Scalo the zones labelled as "industrial" comprise mostly handicraft, commercial and service uses. Once again, the true vulnerability of these activities is "hidden" behind the "industrial" label. The case study shows that commercial activities suffer mostly damages to the goods they sell, which is not the case for service companies or touristic activities like hotels where most damages are to the building and the equipment. In contrast, for handicraft enterprises, the most significant damages are to the equipment. In addition, no measures were taken to prevent damages to either of these economic activities.

Another lesson learned in the Umbria case study is that commercial activities vary also with respect to the indirect damages they can cause, as in the case of pollution of flood water that can affect both the environment and human health. This is mostly related to the materials they sell and have in stock. An example from the case study involves a shop that sold paint. The presence of paint was reported in flood water by several affected companies. If the businesses in Orvieto Scalo had had other chemicals in stock, it could have been worse. In this respect, a positive aspect of zoning in land use maps is that they distinguish gas stations from other types of services. This is important because they can be a source of pollution during flood events. In fact, in Orvieto Scalo, the presence of fuel was reported in flood water, probably from the gas station that was flooded.

Additional lessons learned regard flood hazard maps. The application of the disaster forensic investigation for the study of the flood in Orvieto Scalo and Ciconia revealed that an analysis of this kind represents an opportunity to correct and improve existent hazard maps. Hazard maps show the expected flood extensions associated with different return periods. These return periods are based on the historical time series of flood discharge measured in river sections, which are generally not long enough to permit an accurate assessment of the more extreme events (i.e. larger return periods) that vastly exceed the number of years of measurements. Therefore, the assessed flood-prone areas can change due to both a better availability of data or due to hazard aggravation from factors like floodplain development or climate change. Moreover, flood-prone areas, like the “PAI bands”, are determined through hydraulic modelling. There are always limitations on the use of models, even more so because these models are usually one-dimensional hydraulic models. It is important to note as well that flood-prone areas such as the PAI bands are not fixed lines that distinguish hazardous areas from “safe” areas. As mentioned, these lines show what the expected flooded area is for a given return period (e.g. 50, 100, 200 or 500 years). The return period represents a probability of flood occurrence. Therefore, the flood-prone areas are associated to a probability of occurrence, which means that if we consider more “extreme scenarios”, i.e. floods with a lower probability of occurrence (higher return period) the flood-prone area could be bigger than the one shown in the maps.

Moreover, the Umbria case study also shows that spatial planning contributed to the increase of exposure and vulnerability in flood-prone areas and, thus, on the resulting flood risk. Constraints to development from basin plans were enforced too late. However, there are still lots that are vacant inside band A that are waiting for investments to be developed. Construction in these plots would increase flood risk. In Ponticelli, these lots are owned by the municipality, who does not apply the norms from basin plans because the planning instruments were already approved. Last, there was no reconstruction planning nor incentives for affected enterprises to take measures to lower their vulnerability, even if accessing to public compensation. Therefore, there was no build back better.



Lessons Learned

- Zoning categories do not reflect vulnerability to floods, in particular for industrial and commercial activities.
- Important damages to handicraft, industries and commercial activities in Orvieto Scalo, which did not take any measures to prevent them.
- Deficiencies in flood hazard maps in force.
- Spatial planning contributed to the increase of exposure and vulnerability in flood-prone areas, and therefore on the increase of flood risk.
- Vacant plots waiting for development in band A, because norms from basin plans are not applied to instruments already in force.
- No reconstruction planning nor incentives for affected enterprises to take measures to lower their vulnerability. No build back better.

DRR measures in Spatial Planning for risk reduction:

- Measures for existing economic activities.

Spatial Planning as DRR measure for risk reduction:

- Relocation of gas station from flood-prone area.
- Pre-event reconstruction planning.

Spatial Planning as DRR measure for risk prevention:

- Land use categories more tailored to their vulnerability to floods.

Spatial Planning as DRR measure for risk reduction:

- Transformation of existing land use in land use with lower vulnerability.

DRR measures in Spatial Planning for risk prevention:

- New constructions with measures to prevent damages.

Spatial Planning as DRR measure for risk prevention:

- Land-use categories tailored to their vulnerability to floods.
- Vulnerability/exposure mitigation as conditions for public compensation.

Figure 136 Lessons learned in Umbria case study and proposed actions by category (source: author).

Figure 136 synthesises the lessons learned from the application of the Disaster Forensic Investigation in the Umbria case study. It shows that these lessons are added to the DRR knowledge base in spatial planning. Different types of actions are proposed based on this DRR knowledge.

The actions that are proposed for the Umbria case study based on the lessons learned are of many kinds. The actions on the existent built environment and "as is" situation comprise the introduction of DRR measures in spatial plans and the use of spatial plans as instruments for risk reduction (i.e. spatial planning as DRR measure). The former concern the introduction of measures to lower the vulnerability of existing economic activities in Orvieto Scalo and Ciconia to reduce existing flood risk and prevent damages from potential floods. The forensic investigation revealed that no measures were taken by businesses to prevent damages, even though business owners recognised there were some measures that they could have taken that would have reduced the damages they suffered in the 2012 flood. Possible measures to reduce flood risk, and prevent the damages of potential future floods, include building floodproofing and moving the storage of goods to higher levels. This last measure is particularly important for commercial activities, which suffered damages mostly to goods, and for manufacturers like the technology company affected in Ciconia. Another action to reduce flood risk for the existent built environment is the relocation of gas stations from Orvieto Scalo to safer areas to avoid pollution and environmental damage in case of flooding. The last action to reduce flood risk in the existent built environment is the anticipation of a reconstruction plan for possible future flood events, considering the mitigation measures that could be taken by the economic activities to lower their exposure and vulnerability. These measures should be defined by type of enterprise.

The actions proposed in the future built environment are of three kinds. First, for risk prevention in future local plans, it is proposed to define new zoning categories that consider better the vulnerability of different land uses to floods. As the lessons learned show, commercial, handicraft and industrial activities have different vulnerabilities. Moreover, there are also differences in the vulnerability of economic activities within the industrial sector. This knowledge would permit planners to select better the land uses for areas that are to be developed. Second, for risk reduction, it is suggested to transform some of the existing land-uses in land use with lower vulnerability, especially for the vacant plots that are still to be developed. Lessons learned show that in Ponticelli there are vacant plots in very hazardous areas, which are even in possession of the municipality, waiting for investors to be developed. Last, it is proposed to introduce DRR measures in spatial plans to prevent damages in new constructions. These could be introduced through building regulations for new constructions and redevelopment that introduce measures like floodproofing, the prohibition to build underground, differentiated uses by floors (limiting exposure in lower levels), etc.

For action on both the existent and future built environment in other similar areas, it is proposed to define new zoning categories that consider better flood vulnerability, based on the lessons learned in Umbria. This would permit planners to define better the land uses in flood-prone areas (even in zones with a low probability of flooding) for redevelopment, transformations and new development. Last, it is proposed to make vulnerability and exposure mitigation conditions for accessing to public compensation.

7.4 AT WHAT PLANNING LEVELS TO INTRODUCE THE NEW DRR KNOWLEDGE AND ACTIONS TO MAINSTREAM FLOOD RISK MANAGEMENT?

As we have seen, the actions based on the lessons learned from the Disaster Forensic Investigation can be of different types. The level of spatial planning in which these actions could be introduced depends largely on the characteristics of the instruments at each level. This, at the same time, rests on the planning system of each country. Therefore, the first part of the analysis will be based on the review in Chapter 2 on the state of the art of the DRR knowledge base on floods in Italian Regional Planning and in Local Planning in selected EU countries. The Italian, French and German cases will be used as examples to show how the DRR knowledge and the related actions from the Grimma and Umbria case studies could be introduced in existing planning instruments.

The second part of the analysis links Disaster Forensic Investigation to actions and measures to mainstream flood risk management in spatial planning. A new taxonomy of flood risk prevention and reduction measures is developed that, in association to the lessons learned from Disaster Forensic Investigation, supports the selection of actions to effectively mainstream flood risk management in spatial planning at different levels. This taxonomy is useful for other countries and planning systems, given that it can be adapted according to the scope of their planning instruments.

7.4.1 Integration of DRR knowledge and actions in Regional and Local Planning in selected EU countries

We have seen in Chapter 2 how recent Italian Regional plans show a common need to overcome the traditional approach of separating the different types of regional planning with a new mixed model that is simultaneously strategic, structural and operational (De Luca & Lingua, 2014). This new trend in regional planning represents an opportunity for integrating DRR knowledge from Disaster Forensic Investigation and actions for flood risk prevention and reduction. Flood risk prevention and reduction can be, and currently is in some cases (see Chapter 2), integrated into the strategies, objectives, goals and actions of the plans. In order to ensure that flood risk prevention and reduction are pursued also in planning instruments at lower levels, it needs first to be embedded within the goals and objectives of the Regional plan.

As these recent regional plans show, regional planning not only can provide common goals and a vision for the future, but it can define a way to achieve them through different actions. These actions must be based on knowledge and evidence. Yet, the analysis of the present state of regional plans showed that even if these actions comprise a wide range of measures for flood risk prevention and reduction, they are not supported by a likewise broad range of knowledge and evidence. As a matter of fact, the knowledge base of the plans covers at most the hazard aspect of risk and is, therefore, not enough to support these actions for flood risk prevention and reduction. There is then an opportunity to introduce in the current DRR knowledge base the lessons learned from Disaster Forensic Investigation. These lessons learned would permit to inform a wide range of actions to prevent and reduce risk in current regional plans.

This new trend in Italian Regional planning makes some of the actions proposed within the case studies suitable to be introduced at the Regional level. For example, the insurance scheme proposed for the Grimma case, if it were in Italy, instead of setting it at State level it could be set at the Regional level and introduced in the regional plan. It would be the Region the authority that would impose constraints on floodplain development to the municipalities. This would be achieved through both the regional plan and accompanying regional legislation (as done with other actions like the introduction of the hydraulic invariance principle).

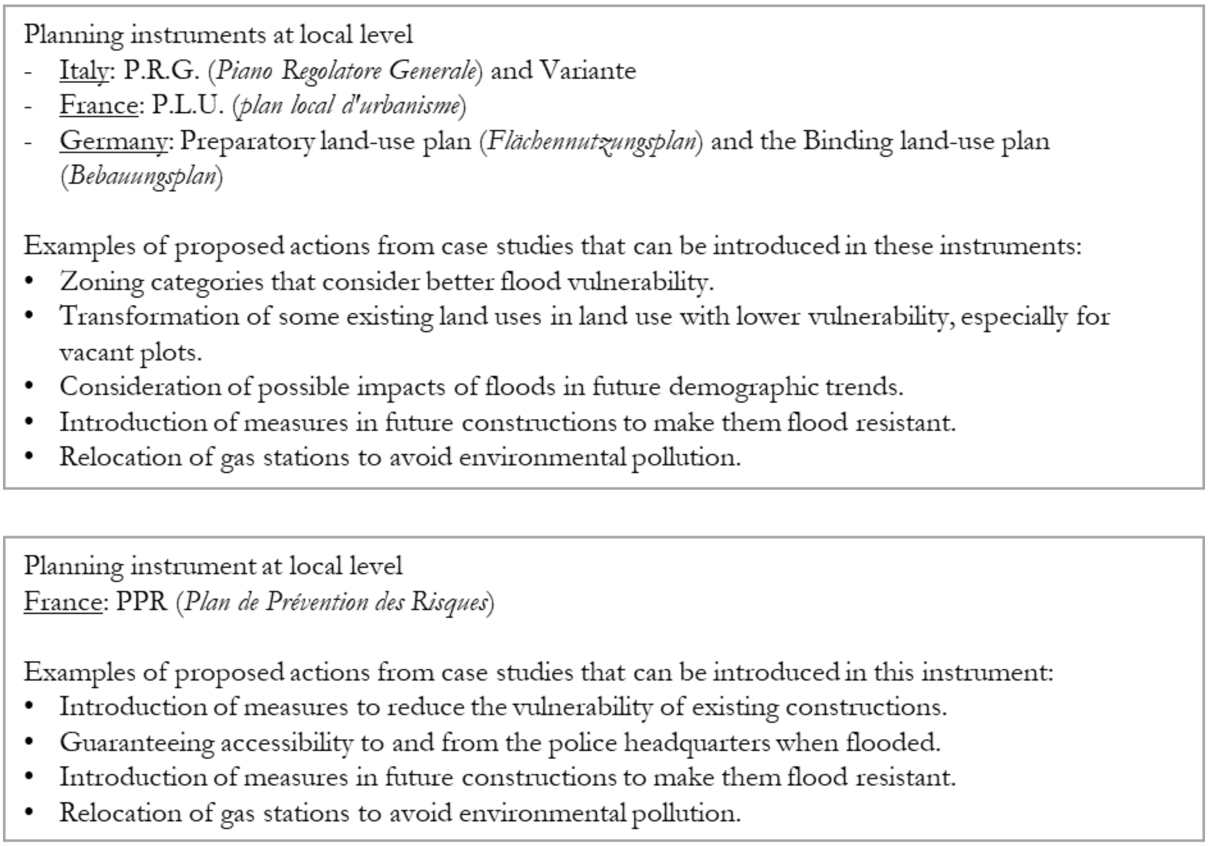
The review in Chapter 2 also shows that spatial planning instruments at the local level differ in the three analysed countries, i.e. Italy, France and Germany. These planning instruments have different scopes. Regardless, Disaster Forensic Investigation can enhance the DRR knowledge base that supports all these kinds of planning instruments. However, the actions that can be proposed based on this knowledge will depend on the reach of each planning instrument. For example, the Plan de Prévention des Risques (PPR, Risk Prevention Plan) in France can act on both existing constructions and future ones. In contrast, the (more or less detailed) land use plans at municipal level present in all three countries act mostly on new development, redevelopment or land use transformations.

To illustrate this aspect, the actions proposed in the case studies are organised according to a possible introduction within existing local planning instruments in Italy, France and Germany. The instruments' scope in terms of the possibility of modifying the existent built environment is the most important aspect considered for defining the possible planning instruments in which to introduce these actions. As mentioned, the PPR in France has a wider scope in this respect because it focuses also on existent constructions for reducing flood risk and, thus, allows the introduction of a wider range of measures for reducing existing risk. However, the PPR is a plan that focuses on risks and not a traditional land-use plan. Consequently, some measures related to land-use planning cannot be integrated into this plan. Conversely, the P.R.G. in Italy, the P.L.U. in France and both the preparatory and the binding land-use plans in Germany are traditional land-use plans that address mostly new development and redevelopment.

Considering the actions defined for the case studies, the P.R.G. (Italy), the P.L.U. (France) and the preparatory and binding land-use plans (Germany) are suitable for: the introduction of new zoning categories that represent better flood risk vulnerability; the transformation of some land-uses in others with lower vulnerability (especially for still undeveloped plots); the consideration of possible impacts of floods in demographic trends; new constructions that are floodproof and the relocation of gas stations from flood-prone areas. In contrast, the PPR in France can include measures to reduce the physical vulnerability of existing constructions in flood-prone areas, measures to guarantee the accessibility to and from the police headquarters when flooded, the relocation of existing gas stations and measures for new floodproof constructions.

Figure 137 presents the actions from the case studies that could be introduced in the Italian, French and German planning instruments at the local level. It lists the actions identified for the Grimma and

Umbria cases according to the local planning instruments where they could be integrated. Planning instruments are classified in two groups considering their characteristics and their scope in addressing the existent and the future built environment. Hence, the P.R.G. (Italy), the P.L.U. (France) and the preparatory and binding land-use plans (Germany) are land-use plans (more or less detailed) that address mostly future development and redevelopment, whereas the PPR (France) is an essential instrument of action for risk prevention and for reducing the vulnerability of people and assets to natural hazards.



Planning instruments at local level
- Italy: P.R.G. (*Piano Regolatore Generale*) and Variante
- France: P.L.U. (*plan local d'urbanisme*)
- Germany: Preparatory land-use plan (*Flächennutzungsplan*) and the Binding land-use plan (*Bebauungsplan*)

Examples of proposed actions from case studies that can be introduced in these instruments:
- Zoning categories that consider better flood vulnerability.
- Transformation of some existing land uses in land use with lower vulnerability, especially for vacant plots.
- Consideration of possible impacts of floods in future demographic trends.
- Introduction of measures in future constructions to make them flood resistant.
- Relocation of gas stations to avoid environmental pollution.

Planning instrument at local level
France: PPR (*Plan de Prévention des Risques*)

Examples of proposed actions from case studies that can be introduced in this instrument:
- Introduction of measures to reduce the vulnerability of existing constructions.
- Guaranteeing accessibility to and from the police headquarters when flooded.
- Introduction of measures in future constructions to make them flood resistant.
- Relocation of gas stations to avoid environmental pollution.

Figure 137 Example of actions to introduce in local planning instruments (source: author).

7.4.2 Link between Disaster Forensic Investigation and flood risk management mainstreamed in spatial planning

Lessons learned from Disaster Forensic Investigation permit to base actions for flood risk prevention and reduction in spatial plans. In this way, flood risk management can be mainstreamed in spatial plans at different levels. In order to support the selection of these actions to mainstream flood risk management in spatial plans, a new taxonomy of flood risk prevention and reduction measures is developed. This taxonomy, in association with the lessons learned from Disaster Forensic Investigation, will support the definition of actions to integrate into spatial plans in flood-prone areas. This taxonomy is useful regardless of the country and planning system because it can be adapted according to the scope of existing planning instruments. Lessons learned from the application of the Disaster Forensic Investigation method, as developed in this research, in conjunction with this new taxonomy support the mainstreaming of flood risk prevention and reduction in spatial plans in flood-prone areas.

Flood risk prevention and reduction measures are classified according to five criteria: (i) the factor on which the measure acts (e.g. hazard, exposure, vulnerability), (ii) the measure typology (i.e. structural, non-structural), (iii) action on the existent or the future built environment, (iv) decision maker, and (v) planning level of introduction (i.e. regional, local). This new taxonomy elaborates and retains from the one proposed by the author in Pesaro et al. (2018) the categories (ii) and (iv) on whether the measure is structural or non-structural and on the measure's decision-maker, respectively. The defined criteria are useful for the selection of flood risk management measures to integrate into spatial planning at different levels. They are explained in detail next.

The classification according to the factor on which the measure acts refers to the following:

- the hazard,
- the exposure of the built environment and people,
- the physical vulnerability of the built environment,
- the systemic vulnerability of networks and infrastructure,
- the vulnerability of the economic system and
- the vulnerability of the social system.

This first criterion links the results of the Disaster Forensic Investigation to the selection of possible risk prevention and reduction actions. These measures act on the factors identified during the forensic investigation that had an important weight in the disaster damages and impacts, as defined in the framework of the new disaster forensic investigation method (Figure 130). Measures classified under the category "vulnerability of the economic system" and of the "social system" contribute to the reduction of these vulnerabilities and to the increase of economic and social resilience.

The typology of the measures refers to whether it is a structural or non-structural measure. Following the terminology by the UNISDR (2017a): "Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems". In contrast, "non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts" (UNISDR, 2017a).

The criterion according to whether the measure acts on the existent or on the future built environment follows the classification that has already been presented in section 7.3. This differentiation acts as guidance for distinguishing the planning instrument in which these measures could be integrated. This aspect is very much related to the scope of the planning instrument.

As we explain in Pesaro et al. (2018), flood management measures involve public and private decision-making. Considering the main decision-makers involved in the implementation of each measure is another important aspect that can support the selection of measures. Following our classification in

Pesaro et al. (2018), these were categorized as "public", "public-private", "private firms" (economic subject) and "private individuals".

The last criterion regards the planning level at which the measures can be introduced. This category is extremely dependent on the country, territorial/administrative areas and planning systems, which determine the planning instruments in place and their scope. Building on the results from the previous section, these are classified in "Regional" and "Local". These categories can be adapted in accordance with a specific planning and administrative system, where for instance instead of regional it could be at the state level.

Table 56 to Table 59 show the new taxonomy with examples of flood risk management measures, taken from the analysis of current Italian Regional plans (Chapter 2) and from the review in Pesaro et al. (2018). These are possible measures to mainstream flood risk prevention and reduction in spatial plans. This table must be used after the application of the Disaster Forensic Investigation in order to define actions that are based on that evidence and that target the identified factors.

Measures that mitigate the hazard (Table 56), may this be structural like levees and detention basins or non-structural like the designation of retention areas, should be coordinated between basin planning and regional planning. Most of these measures require to be defined at a basin level because that is the spatial scale of the phenomenon, i.e. the flood. Actions in a river section have effects downstream. Similar dynamics apply to the whole basin, where actions in an area can impact others. After these measures are set in basin plans, they must be coordinated at lower planning levels. This means also that spatial plans at lower levels must include these measures within the plan's project, by considering how a measure of this kind can be integrated into the territory and within a specific context. The Grimma case study taught us the importance of the design of these structural measures and how a bad design, which is not sensitive to its context, can lead to longer construction times (that is if the project is not abandoned) that in the end translated into damages when the 2013 flood arrived "too early".

Measures that address the physical vulnerability of the built environment (Table 57) comprise both structural and non-structural measures. They can act on the existent built environment by reducing the existing vulnerability or on the future built environment, by preventing vulnerable constructions. The main decision-maker depends on the case. Measures related to land-use planning and regulations must be decided by the public sector. In contrast, building flood-proofing and the change of use of lower levels in buildings, when not normed, must be decided by the private firms or the individuals. Land-use measures must be introduced at the local level, whereas regulations regarding the floodproofing of infrastructures could be introduced at the regional level.

Measures for preventing and reducing the exposure of the built environment and the people (Table 58) are mostly non-structural. They address both the future and the existent built environment. The decision-maker changes according to the measure and sometimes depends on how the measure is implemented. For example, concerning the relocation from hazardous areas, if it is a mandatory relocation, then the main decision-maker is public. If it is voluntary, the decision must be taken by the economic subject (in case of businesses) or the private individual (for residences).

Proposed measures to reduce the systemic vulnerability of networks, infrastructures, the economic system and the social system (Table 59) are all non-structural. They can act on both the existent and the future built environments. The main decision-maker varies according to the measure. For example, measures for reducing the systemic vulnerability of infrastructure can be decided by the public sector for the infrastructure that they own or by making it mandatory through regulation at the regional level. Instead, if the infrastructure is owned by an economic subject, or in exceptional cases by a private individual, this decision must be taken by them. A similar situation concerns the measures to reduce the vulnerability of the economic system. Mandatory flood insurance schemes can be set for both existent and future constructions by the public sector, at either the regional level or a higher level, such as the national. If flood insurance is not mandatory, the decision is left to the economic subjects and individuals.

Table 56 Flood risk management measures for hazard reduction (source: author).

Factor on which the measure acts	**Flood risk prevention and reduction measures**		**Action on**		**Main decision-maker**				**Planning level of introduction**		**Comments**
	Structural measure	**Non-structural measure**	**Existent built environment**	**Future built environment**	**Public**	**Public-Private**	**Private firms (economic subject)**	**Private-Individual**	**Regional**	**Local**	
Hazard		Regulation such as the hydraulic invariance principle	✓	✓	✓				✓ **or upper**		Action on existent/future b. env. depend on regulation.
		Retention areas designation		✓	✓	✓			✓ **or upper**	✓	Should be defined at basin level.
		Environmental protection designations		✓	✓				✓	✓	-
	Levees - flood walls		✓		✓				✓ **or upper**	✓	Should be defined at basin level.
	Diversions and channel improvements		✓		✓				✓ **or upper**		Should be defined at basin level.
	Detention Basins		✓		✓				✓ **or upper**		Should be defined at basin level.
	Urban Drainage and pumping		✓		✓				✓ **or upper**		Should be defined at basin level.

Table 57 Flood risk management measures for reducing physical vulnerability (source: author).

Factor on which the measure acts	**Flood risk prevention and reduction measures**		**Action on**		**Main decision-maker**				**Planning level of introduction**		**Comments**
	Structural measure	**Non-structural measure**	**Existent built environment**	**Future built environment**	**Public**	**Public-Private**	**Private firms (economic subject)**	**Private-Individual**	**Regional**	**Local**	
Physical Vulnerability of built environment		Building regulations and enforcement	✓	✓	✓				✓	✓	-
		Regulations for public buildings and infrastructure	✓	✓	✓				✓	✓	-
		Spatial planning that outlines land uses compatible with the hazardousness of the territory		✓	✓					✓	-
		Change of use of lower levels of buildings	✓					✓	-	-	Not mandatory. If so, would be in building regulations.
		Land-use transformations in favour of lower vulnerability	✓		✓					✓	-
	Building flood-roofing (dry proofing, sealing, etc.)		✓	✓			✓	✓	-	-	Not mandatory. If so, would be in building regulations.
	Infrastructure flood-proofing		✓	✓	✓		✓	✓	✓	✓	-

Table 58 Flood risk management measures for reducing exposure (source: author).

Factor on which the measure acts	**Flood risk prevention and reduction measures**		**Action on**		**Main decision-maker**				**Planning level of introduction**		**Comments**
	Structural measure	**Non-structural measure**	**Existent built environment**	**Future built environment**	**Public**	**Public-Private**	**Private firms (economic subject)**	**Private-Individual**	**Regional**	**Local**	
Exposure of built environment and people		Land use planning avoiding flood-prone areas, prohibition to build in flood-prone areas		✓	✓					✓	-
		Location of public buildings and infrastructure		✓	✓				✓	✓	-
		Relocation from hazardous areas	✓		✓		✓	✓	✓	✓	-
		Prohibition to build underground levels		✓	✓					✓	-
	Raising buildings		✓	✓			✓	✓			Not mandatory. If so, would be in building regulations.

Table 59 Flood risk management measures to reduce systemic vulnerability (source: author).

Factor on which the measure acts	**Flood risk prevention and reduction measures**		**Action on**		**Main decision-maker**				**Planning level of introduction**		**Comments**
	Structural measure	**Non-structural measure**	**Existent built environment**	**Future built environment**	**Public**	**Public-Private**	**Private firms (economic subject)**	**Private-Individual**	**Regional**	**Local**	
Systemic Vulnerability of networks and infrastructure		Network design considering redundancy	✓	✓	✓		✓	✓	✓	✓	-
Vulnerability of social system		Education programmes			✓				✓		-
Vulnerability of economic system		Risk transfer (by means if (re-) insurance or relief funds) for private assets	✓	✓			✓	✓	-	-	-
		Risk transfer (by means if (re-) insurance public assets	✓	✓	✓				✓		-
		Mandatory flood insurance frameworks in flood-prone areas	✓	✓	✓				✓ **or upper**		-

7.5 WHO COULD PERFORM THE DISASTER FORENSIC INVESTIGATION?

So far, the analysis has focused on the use of the Disaster Forensic Investigation tool for supporting spatial planning at different levels. Another issue regards the application of this analysis, which then would be used to support the development of spatial plans at different levels. In the following, I will present a reflection on possible institutions, organisations and authorities that could be in charge of performing the Disaster Forensic Investigation in Italy, France and a general scenario for the EU and other countries. This last scenario will be presented first because it is interconnected with the collection and recording of disaster damage data. As we have seen, the availability and quality of disaster damage data condition the application of the forensic investigation. An important criterion for the selection of the organisations that can be mandated with this task is that they possess technical competencies to develop an analysis of this kind.

A possibility that would be applicable in most countries, and especially in the EU, would be the set-up of a "data coordinator", which was suggested by the Joint Research Centre (De Groeve et al., 2015) for the collection and recording of disaster damage data. This would be a new governmental organisation at either the national or sub-national level, according to the governmental system of each country, responsible for collecting and recording disaster damage data for different purposes and usages. However, I think that the data coordinator should also perform different kinds of data analysis that can support many purposes, including forensic investigation. An advantage of this scenario is that one organisation can both record the disaster damage data and perform different data analyses that are useful for many purposes (e.g. reporting for the Sendai Framework, compensation as for the EU solidarity fund, forensic investigation, etc.). The disadvantage would be that it is an entirely new entity that requires also important coordination with other existing organisations that should collect the data, with all the negative aspects that this could entail (e.g. higher costs).

In Italy, the Regions are the authorities that could be in charge of applying the Disaster Forensic Investigation after the occurrence of damaging events in their territories. The Regions count with technical personnel of different kinds that possess the competencies for applying the analysis. An advantage of this scheme is that it involves an existing administration, so the cost of implementation would be lower than in the case of a data coordinator. An important negative aspect is that a significant effort would be anyway needed for obtaining the required data from other organisations and administrations at lower levels (that is, *if* disaster damage data are even collected by these other entities).

In France, the State with the affected municipalities could apply the Disaster Forensic Investigation, as they develop together the PPR (Risk Prevention Plan). This would be a similar situation as the one proposed for Italy, with the same advantages and disadvantages. However, an important difference and advantage of this scheme with respect to the Italian one is the fact that the State and the Municipality work together in the development of the forensic investigation. The Disaster Forensic Investigation must be applied at the local level to effectively distinguish the causes of the disaster and its impacts. Therefore, the municipality's insights and knowledge would certainly be useful for the analysis.

Moreover, this could have other potential benefits, like raising risk awareness in municipalities and easier integration of the results of the forensic investigation in local planning.

8 CONCLUSIONS AND FUTURE RESEARCH

8.1 CONCLUSIONS

Findings of this research support and go beyond the initial hypothesis, that is that Disaster Forensic Investigation can support the development of effective spatial plans at different levels to prevent and reduce flood risk. Indeed, one of the most important conclusions from this research is that a Disaster Forensic Investigation, like the one developed in this Thesis, permits to mainstream flood risk prevention and reduction in spatial plans at different levels. Flood risk management is mainstreamed in spatial planning through (i) the introduction of DRR measures to reduce and prevent risk in planning instruments, and (ii) spatial plans that act as instruments for risk prevention and reduction. In the first case, risk management measures, as currently used in DRR, are integrated into spatial plans. In the second case, spatial planning acts as a DRR measure by itself, for example through locational decisions, land-use planning and building regulations that are sensitive to flood risk.

Furthermore, as shown in the case studies of Umbria and Grimma, the lessons learned extracted through the Disaster Forensic Investigation can be added to the knowledge base (*Quadro conoscitivo*) used at different planning levels. Consequently, these lessons learned act as DRR knowledge on which to base actions for risk prevention and reduction, integrated into spatial plans at different levels.

In this respect, the new Disaster Forensic Investigation method developed in this research is a comprehensive analysis of a disaster that extracts lessons learned regarding the causes of the disaster and its damages and concerning the role of spatial planning in shaping disaster risk. This last point considers both negative and positive aspects, i.e. whether spatial planning is a risk driver or whether spatial planning contributed to disaster risk prevention and/or reduction. In this research, the new Disaster Forensic Investigation method was applied to the analysis of floods; however, it could be also used to study other kinds of disasters. This research shows how the lessons learned from an analysis of this kind support the definition of actions towards flood risk prevention and reduction for both the existent and the future built environment (new and redevelopment). Besides, some lessons learned can be also used for mainstreaming flood risk management in spatial planning in areas similar to the one analysed in the forensic investigation.

8.2 FINAL REFLECTIONS AND FUTURE RESEARCH

This research is innovative in many ways, primarily through the exploration of the use of a very recent tool for disaster damage data analysis (Disaster Forensic Investigation) for supporting spatial planning processes in flood-prone areas. In fact, Disaster Forensic Investigation was originally created to inform DRR policy-making and practice and never used to support spatial planning practices. This innovate aspect also entails exploring the planning level and related planning instruments into which to introduce the knowledge from the forensic investigation. An additional innovation of this research is the development of a new Disaster Forensic Investigation method, designed to overcome the shortcomings of existing approaches.

The multiple innovative aspects of this research bring about multifaceted issues that can be the starting point for future research. Findings of this research reveal that Disaster Forensic Investigation is an effective tool for mainstreaming flood risk management in spatial planning practices for risk prevention and reduction. The lessons learned from Disaster Forensic Investigation allow basing action for risk prevention and reduction at both regional and local planning levels. This is true for the Italian, German and French cases; however, findings also suggest that this tool could have a wider use in supporting planning processes in other contexts. If this was the case, further research would be required for identifying suitable planning instruments into which to introduce the knowledge from disaster forensic investigation.

This research has taken the first step in exploring the introduction of Disaster Forensic Investigation in spatial planning. Further research should be conducted in order to effectively integrate this tool in a specific context/country. Research must consider the interactions not only between instruments at multiple spatial levels but also between the numerous actors involved in the planning process. This multi-scalar reality with multiple stakeholders and planning instruments often brings about coordination problems. This is an issue that requires more attention but that is in any case present regardless of the knowledge and tools of analysis informing spatial planning.

In addition, further research and efforts must still be directed to both the collection and recording of disaster damage data that serves multiple purposes and usages, including forensic investigation. Even if policies at different levels have called for the collection and recording of disaster damage data, this is still under each country's discretion. In Europe, through the JRC (Joint Research Centre), attention has been given recently to the study of the requirements for disaster damage data collection and recording. Yet, there is up to date no specific legislation addressing the matter. Consequently, more efforts should be devoted to the advancement of said legislation and policies that also consider the roles and mandates of relevant actors and institutions in the process. On the other hand, more research is required to support the development of these policies.

To conclude, returning to the initial quote by White (1945: 2), “Floods are "acts of God," but flood losses are largely acts of man”, it is clear that floods to some extent can be thought of as acts of God, but flood damages *must* be addressed as acts of man. This is what originally drove me to the present research and hence lead me to explore and design a forensic investigation tool to mainstream flood risk management in spatial planning to prevent and reduce damages.

REFERENCES

Atun, F. and Menoni, S. (2017). Cities: places of complexity, in *EDUCEN Culture & Urban Disaster, A Handbook,* Netherland. DOI: http://dx.doi.org/10.18174/417184.

Ballio F., Menoni, S., Minucci, G., Molinari, D. et al. (2013). Lo Scenario di Danno in Seguito all'Alluvione di Novembre 2012 nella Regione Umbria. I risultati dell'Attività di Rilievo e di Analisi dei Danni, report, Politecnico di Milano.

Barbetta S., Brocca L., Caminici S. Moramarco T., Tarpanelli A. (2013). Studio evento piena 11-14 Novembre 2012 (Paglia-Chiani e Nestore) - Ricostruzione delle aree allagate per il torrente Chiani e per il fiume Nestore, CNR-Irpi.

Barredo, J. (2009). Normalised flood losses in Europe: 1970–2006. Nat. Hazards Earth Syst. Sci., 9(1), pp.97-104.

Barthelemy F., Huet P., Lefrou C. & Suzanne J.C. (1999). Organisation du retour d'expérience dans le domaine des risques naturels, Conseil Général des Ponts et Chaussées, Mission d'Inspection Spécialisée de l'Environnement, 44 p.

Berni, N. , Molinari, D. , Ballio, F. , Minucci, G. and Munoz, C. A. (2017). Best Practice of Data Collection at the Local Scale. In Flood Damage Survey and Assessment (eds D. Molinari, S. Menoni and F. Ballio). doi:10.1002/9781119217930.ch6

Besio M. (1994). Alcune riflessioni tra progetto di conoscenza e progetto di piano, in Maciocco, G., (Ed.), *La città, la mente e il piano. Sistemi intelligenti e pianificazione urbana*, Milano, Angeli.

Burby, J. R. (1998). Natural Hazards and Land Use: An Introduction. In: Burby, J. R., (Ed.), *Cooperating with Nature*. Washington DC: Joseph Henry Press, 1-26.

Campania Region (2007). Dissesto Idrogeologico, available at: http://www.difesa.suolo.regione.campania.it/content/category/6/25/37/ (accessed June 2018).

Carper, K. (1989). *Forensic engineering*. New York: Elsevier.

Carta, M. (1996). *Pianificazione territoriale e urbanistica, Dalla conoscenza alla partecipazione*. Palermo: Medina.

CEDIM (2013). CEDIM Annual Research Report 2012 - Focus on Forensic Disaster Analysis in Near Real-Time, Center for Disaster Management and Risk Reduction Technology.

CFU, Centro Funzionale Regione Umbria (2012). Evento Alluvionale 11-14 Novembre 2012, Rapporto di Evento, Direzione Programmazione, Innovazione e Competitività dell'Umbria, Servizio Protezione Civile, Regione Umbria.

Community initiative LABEL (2012). Elbe Atlas, Dresden, Germany.

De Groeve, T., Poljansek, K., Ehlrich, D., (2013). Recording Disaster Losses: Recommendations for a European approach. Report by the Joint Research Centre of the European Commission 10/2013; doi: 10.2788/98653.

De Groeve, T., Poljansek, K., Ehlrich, D., Corbane, C. (2014). Current Status and Best Practices for Disaster Loss Data recording in EU Member States: A comprehensive overview of current practice in the EU Member States. Report by Joint Research Centre of the European Commission, JRC92290, doi: 10.2788/18330, available at http://drr.jrc.ec.europa.eu/Portals/0/Loss/JRC%20SOTA%20Loss%20Report_11182014.pdf

De Groeve, T., Corbane, C., Ehlrich, D. (2015). Guidance for Recording and Sharing Disaster Damage and Loss Data. Report by Joint Research Centre of the European Commission, doi:10.2788/186107, available at http://drr.jrc.ec.europa.eu/Portals/0/Loss/JRC_guidelines_loss_data_recording_v10.pdf

De Luca, G., & Lingua, V. (2014). Evolution in regional planning: the Italian path, Iconarp International Journal of Architecture and Planning, [S.l.], v. 2, n. 2, p. 14-33, feb. 2015. ISSN 2147-9380. Available at: http://iconarp.selcuk.edu.tr/iconarp/article/view/61/42. (accessed Nov. 2018).

DKKV, German Committee for Disaster Reduction (Ed.) (2012). Detecting Disaster Root Causes – A Framework and an Analytic Tool for Practitioners. DKKV Publication Series 48, Bonn.

Eburn, M. and Dovers, S. (2015). Learning Lessons from Disasters: Alternatives to Royal Commissions and Other Quasi-Judicial Inquiries. *Australian Journal of Public Administration*, 74(4), pp.495-508.

Elmer, F., Haubrock, S., Kreibich, H., Seifert, I., Thieken, A. (2007). HOWAS21 – Conceptual Framework and Configuration of an object-specific Flood Damage Database for Germany, 8. Forum DKKV/CEDIM: Disaster Reduction in Climate Change 15./16.10.2007, Karlsruhe University.

Esteban, J.F., Izquierdo, B., Lopez, J., Molinari, D., Menoni, S., De Roo, A., Deeming, H., Walker, G. and Eftichidis, G. (2011). Current Mitigation Practices in the EU, in Inside risk: A Strategy for Sustainable Risk Mitigation, Springer.

European Commission (2013). Technical Report - 2013 – 071, Guidance for Reporting under the Floods Directive (2007/60/EC), Guidance Document No. 29, European Union, ISSN 1725-1087, ISBN 978-92-79-33168-8, doi: 10.2779/50095.

European Safety Reliability and Data Association (ESReDA) (2009). Guidelines for Safety Investigation of Accidents, ISBN 978-82-51-50309-9.

Federal Ministry of the Interior, Germany (2017). Civil Protection, available at www.bmi.bund.de/EN/topics/civil-protection/civil-protection-node.html (accessed October 2017).

Fleischhauer, M. (2005). Country Report: France, in *Report on the European scenario of technological and scientific standards reached in spatial planning versus natural risk management*, Greiving, S., Fleischhauer, M., Wanczura, S. (Eds.), Deliverable 1.1, Armonia Project.

Fornace della Memoria (2018). Storia della Fornace, available at http://www.fornacedellamemoria.org/

Friedmann, J. (1993). Toward a Non-Euclidian Mode of Planning. *Journal of the American Planning Association*, 59(4), pp.482-485.

Galderisi, A., Profice, A. S. (2012). Land Use Planning, Sustainability and Risk Mitigation: Towards an Integration, In *Land Use Planning, Regulations and Environment*, Aubrecht, S., Freire, S., Steinnocher, K. (Eds.), Nova Science Publishers, Inc., New York.

Gall, M., Borden, K. and Cutter, S. (2009). When Do Losses Count?. *Bulletin of the American Meteorological Society*, 90(6), pp.799-810.

Gall, M., Emrich, C. T., Cutter, S. (2014). Who needs loss data? Background paper prepared for the 2015 Global Assessment Report on Disaster Risk Reduction, Hazards & Vulnerability Research Institute Department of Geography, University of South Carolina Columbia, SC, United States of America.

Gazzola, V. (2018). Uso del suolo e riduzione del rischio naturale in ambito urbano, Conoscenza, metodo e strumenti per la ridefinizione funzionale preventiva, PhD Thesis, XXX cycle, Graduate School in Civil Engineering and Architecture, University of Pavia.

GFDRR, Global Facility for Disaster Risk Reduction (2016). The making of a riskier future: How our decisions are shaping future disaster risk, Washington D.C., U.S.A.

Godschalk, D. R. (2003). Urban Hazard Mitigation: Creating Resilient Cities. *Natural Hazards Review,* Vol. 4, No. 3, ISSN 1527-6988/2003/3. 136-143.

Greiving, S. (2005). Country Report: Germany, in *Report on the European scenario of technological and scientific standards reached in spatial planning versus natural risk management*, Greiving, S., Fleischhauer, M., Wanczura, S. (Eds.), Deliverable 1.1, Armonia Project.

Grimma Museum (2002). Bilderflut – Flutbilder, available at: www.museum-grimma.de/index.php/bilderflut-flutbilder.html (accessed June 2017).

Hartmann, T. & Juepner, R. (2013). The Flood Risk Management Plan: An Essential Step Towards the Institutionalization of a Paradigm Shift. International Journal of Water Governance, 2(107), pp.107-118.

Hartmann, T. & Spit, T. (2016). Legitimizing differentiated flood protection levels – Consequences of the European flood risk management plan. Environmental Science & Policy, 55, pp.361-367.

Hubert, G. & Ledoux, B. (1999). Le cout du risque… L'évaluation des impacts socio-économiques des inondations, Presses de l'école nationale des ponts et chaussées.

IPCC Intergovernmental Panel on Climate Change (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G. K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley, eds., A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY.

IPCC Intergovernmental Panel on Climate Change (2014) 'Summary for policymakers'. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IRDR, Integrated Research on Disaster Risk (2011). Forensic Investigations of Disasters: The FORIN Project (IRDR FORIN publication No. 1). Beijing, China.

IRDR, Integrated Research on Disaster Risk (2014). Peril Classification and Hazard Glossary (IRDR DATA Publication No. 1). Beijing: Integrated Research on Disaster Risk.

IRDR, Integrated Research on Disaster Risk. (2015). Guidelines on Measuring Losses from Disasters: Human and Economic Impact Indicators (IRDR DATA Publication No. 2). Beijing: Integrated Research on Disaster Risk.

ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale (2016). Annuario dei Dati Ambientali 2016, ISPRA, Stato dell'Ambiente 69/2016.

Keating, A., Venkateswaran, K., Szoenyi, M., MacClune, K. and Mechler, R. (2016). From event analysis to global lessons: disaster forensics for building resilience. Natural Hazards and Earth System Sciences Discussions, pp.1-25.

Klijn, F., Samuels, P. and Van Os, A. (2008). Towards flood risk management in the EU: State of affairs with examples from various European countries. International Journal of River Basin Management, 6(4), pp.307-321.

Kreibich, H., Thieken, A., Haubrock, S. L, Schröter, K (2017). HOWAS21, the German Flood Damage Database, in *Flood Damage Survey and Assessment: New Insights from Research and Practice,* Molinari, D., Menoni, S., Ballio, F. (Eds.) Geophysical Monograph Series, American Geophysical Union.

Labib, A. & Read, M. (2015). A hybrid model for learning from failures: The Hurricane Katrina disaster. Expert Systems with Applications, 42(21), pp.7869-7881.

Landestalsperrenverwaltung des Freistaates Sachsen (2006). Hochwasserschutz Grimma, Maßnahmekonzept, Landestalsperrenverwaltung, Betrieb Elbaue / Mulde / Untere Weiße Elster.

Lazio Region (2011a). La Regione Lazio tutela il paesaggio, available at: http://www.regione.lazio.it/rl_urbanistica/?vw=contenutidettaglio&id=64 (accessed June 2018).

Lazio Region (2011b). Piano Territoriale Regionale Generale (PTRG), available at: http://www.regione.lazio.it/rl_urbanistica/?vw=contenutiDettaglio&id=45 (accessed June 2018).

Leone, F. (2007) Caracterisation des vulnerabilites aux catastrophes " naturelles ": contribution a une evaluation geographique multirisque (mouvements de terrain, seismes, tsunamis, eruptions volcaniques, cyclones). Geographie. Universite Paul Valery - Montpellier III.

Livingston, A.D., Jackson, G., Priestly, K. (2001). Root causes analysis: literature review, Contract Research Report, Prepared by WS Atkins Consultants Ltd for the Health and Safety Executive 325/2001

Loáiciga, H. (2001). Flood damages in changing flood plains: a forensic-hydrologic case study. Journal of the American Water Resources Association, 37(2), pp.467-478.

Lombardy Region (2018). Invarianza idraulica e idrologica, available at: http://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioServizio/servizi-e-informazioni/Enti-e-Operatori/Territorio/difesa-del-suolo/invarianza-idraulica-e-idrologica/invarianza-idraulica-e-idrologica (accessed June 2018).

Marín Ferrer, M.; Do Ó, A.; Poljansek, K., Casajus Vallés, A. (2018). Disaster Damages and Loss Data for Policy, Publication Office of the European Union, Luxembourg, 2018, JRC110366.

McLoughlin, B. (1969). *Urban & Regional Planning: A Systems Approach.,* London, Faber.

Mendoza, M. T., Menoni, S. (2019, forthcoming). Forensic investigation of disasters to support wiser land use plans.

Menoni, S. (2005). Country report Italy, local level in Report on the European scenario of technological and scientific standards reached in spatial planning versus natural risk management, Greiving, S., Fleischhauer, M., Wanczura, S. (Eds.), Deliverable 1.1, Armonia Project.

Menoni S., Molinari D., Parker F., Ballio F., Tappsel S. (2012). Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies. Natural Hazards 10, 1-26.

Menoni, S., Molinari, D., Ballio, F., Minucci, G., Mejri, O., Atun, F., Berni, N. and Pandolfo, C. (2016). Flood damage: a model for consistent, complete and multipurpose scenarios. Natural Hazards and Earth System Sciences, 16(12), pp.2783-2797.

Merz, B., Kreibich, H., Schwarze, R. and Thieken, A. (2010). Review article "Assessment of economic flood damage". Natural Hazards and Earth System Science, 10(8), pp.1697-1724.

Meyer, V., Becker, N., Markantonis, V., Schwarze, R., van den Bergh, J., Bouwer, L., Bubeck, P., Ciavola, P., Genovese, E., Green, C., Hallegatte, S., Kreibich, H., Lequeux, Q., Logar, I., Papyrakis, E., Pfurtscheller, C., Poussin, J., Przyluski, V., Thieken, A. and Viavattene, C. (2013). Review article: Assessing the costs of natural hazards – state of the art and knowledge gaps. Natural Hazards and Earth System Science, 13(5), pp.1351-1373.

Meyer, V., Priest, S. and Kuhlicke, C. (2011). Economic evaluation of structural and non-structural flood risk management measures: examples from the Mulde River. Natural Hazards, 62(2), pp.301-324.

MIAT/DDSC/SDGR/BAPC (2006). Guide méthodologique « La conduite du retour d'expérience, éléments techniques et opérationnels ».

Ministère de la transition écologique et solidaire (2018). Glossaire, Plan de prévention des risques naturels prévisibles (PPRN), Définition juridique, available at: http://www.georisques.gouv.fr/glossaire/plan-de-prevention-des-risques-naturels-previsibles-pprn-0 (accessed November 2018)

Mohleji, S. & Pielke, Jr., R. A. (2014) Reconciliation of Trend in Global and Regional Economic Losses from Weather Events: 1980-2008, Natural Hazards, doi:10.1061/(ASCE)NH.1527-6996.0000141.

Molinari, D., Menoni, S., Aronica, G. T., Ballio, F., Berni, N., Pandolfo, C., Stelluti, M., and Minucci, G. (2014). Ex post damage assessment: an Italian experience, Nat. Hazards Earth Syst. Sci., 14, 901-916, https://doi.org/10.5194/nhess-14-901-2014.

Moor, J. (2001). Cities at risk. Habitat Debate, 7(4): 4-5.

Noon, R. (2001). Forensic engineering investigation. Boca Raton, FL: CRC Press.

Noon, R. (2009). *Scientific method*. Boca Raton: CRC Press.

NRI-1 (2002). MORT user's manual. For use with the management Oversight & Risk Tree analytical logic diagram (NRI-2). Noordwijk Risk Initiative Foundation (NRI), The Netherlands.

OECD, Organisation for Economic Co-operation and Development (2014). Improving the Evidence Base on the Costs: Towards an OECD Framework for Accounting Risk Management Expenditures and

Losses of Disasters, Issues Paper, available at: https://www.oecd.org/gov/risk/issues-paper.pdf (accessed Nov 2017).

OECD, Organisation for Economic Co-operation and Development (2016). Improving the Evidence Base on the Costs of Disasters, Key Findings from an OECD Survey, Joint Expert Meeting on Disaster Loss Data 26-28 October 2016, GOV/PGC/HLRF(2016)6.

Oliver-Smith, A., Alcántara-Ayala, I., Burton, I. and Lavell, A. (2016) Forensic Investigation of Disasters (FORIN): a conceptual framework and guide to research (IRDR FORIN publication No.2), Integrated Research on Disaster Risk IPO, Beijing, China.

Pahl-Weber, E. & Henckel, D. (2008). The planning system and planning terms in Germany. Hannover: Akademie für Raumforschung und Landesplanung.

Paprotny, D., Sebastian, A., Morales-Nápoles, O. and Jonkman, S. (2018). Trends in flood losses in Europe over the past 150 years. Nature Communications, 9(1).

Park, J., Seager, T. P., Rao, P. S. C., Convertino, M. and Linkov, I. (2013). Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems. *Risk Analysis*, 33(3), pp.356-367.

Pelling, M. (2006). Cities are getting more and more vulnerable. Habitat Debate, 12(4): 6.

Peltier A. (2008). La cartographie réglementaire des risques naturels en Suisse, en Italie et en France, La mise en carte des risques naturels, Diversité des approches, Montpellier: Presses Universitaires de la Méditerranée, coll. Géorisques, n°2, pp. 61-67.

Pesaro, G., Mendoza, M. T., Minucci, G. Menoni, S. (2018) Cost-Benefit Analysis for non-structural flood mitigation measures: Insights and lessons learnt from a real case study. In Haugen, S. (Ed.), Barros, A. (Ed.), Gulijk, C. v. (Ed.), Kongsvik, T. (Ed.), Vinnem, J. (Ed.). Safety and Reliability – Safe Societies in a Changing World. London: CRC Press.

Pipino, L., Lee, Y. and Wang, R. (2002). Data quality assessment. Communications of the ACM, 45(4ve).

Prizzia, R. (2016). Climate Change and Disaster Forensics. In: A. Masys, ed., Disaster Forensics: Understanding Root Cause and Complex Causality, 1st ed. Springer International Publishing Switzerland 2016.

Ramírez, A.I., Herrera Lozano, L. A. (2015). Análisis forense de inundaciones: una guía metodológica, *Tecnología y Ciencias del Agua,* Vol. 6, núm. 1 (2015).

Rammazzina, F. (2013). Analisi Idraulica e Idrologica della Piena del Fiume Paglia nelle Zone di Orvieto Scalo e di Ciconia e Scenario di Esondabilità: Implicazioni per il Sistema delle Infrastrutture e dei Trasporti, BETA Studio s.r.l.

Republique Française (2018). Documents d'urbanisme PLU, POS, carte communale existant sur le département sous forme numérique, available at:

https://www.data.gouv.fr/fr/datasets/documents-durbanisme-plu-pos-carte-communale-existant-sur-le-departement-sous-forme-numerique-1/ (accessed November 2018)

Santos-Reyes, J., Alvarado-Corona, R. and Olmos-Peña, S. (2010). Learning from Tabasco's floods by applying MORT. *Safety Science*, 48(10), pp.1351-1360.

Schanze J, Hutter G, Penning-Rowsell E, Nachtnebel H-P, Meyer V, Werritty A, Harries T, Holzmann H, Jessel B, Koeniger P, Kuhlicke C, Neuhold C, Olfert A, Parker D, Schildt A (2008). Systematisation, evaluation and context conditions of structural and non-structural measures for flood risk reduction. FLOOD-ERA Joint Report, published by ERA-NET CRUE.

Schumann, A., Fischer, B., Büttner, U., Bohn, E., Walther, P., Wolf, E. (2016). Die größten Hochwasser im Einzugsgebiet der Mulde im meteorologisch-hydrologischen Vergleich, Schriftenreihe, Heft 18/2016.

Shuirman, G. and Slosson, J. (1992). Forensic engineering. San Diego: Academic Press.

Siedschlag, D. (2010). Hochwasser & Eigenvorsorge – Untersuchung von Einflussfaktoren persönlicher Schutzmaßnahmen, Master Thesis, UFZ-Bericht 03/2010.

Stefoff, R. (2011). Forensics and modern disasters. New York: Marshall Cavendish Benchmark.

Taylor, I. (2016). Application of Problem Inversion to Cascading Critical Infrastructure Failure. In: A. Masys, ed., Disaster Forensics: Understanding Root Cause and Complex Causality, 1st ed. Springer International Publishing Switzerland 2016.

The European Parliament and the Council of the European Union (2005). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

The European Parliament and the Council of the European Union (2007). Directive on the assessment and management of flood risks (2007/60/EU). Official Journal L 288

Thieken, A., Müller, M., Kreibich, H. and Merz, B. (2005). Flood damage and influencing factors: New insights from the August 2002 flood in Germany. Water Resources Research, 41(12).

Thieken, A., Bessel, T., Kienzler, S., Kreibich, H., Müller, M., Pisi, S. and Schröter, K. (2016a). The flood of June 2013 in Germany: how much do we know about its impacts? Natural Hazards and Earth System Sciences Discussions, pp.1-57.

Thieken, A., Kienzler, S., Kreibich, H., Kuhlicke, C., Kunz, M., Mühr, B., Müller, M., Otto, A., Petrow, T., Pisi, S. and Schröter, K. (2016b). Review of the flood risk management system in Germany after the major flood in 2013. Ecology and Society, 21(2).

Trigila A., Iadanza C., Bussettini M., Lastoria B., Barbano A. (2015) Dissesto idrogeologico in Italia: pericolosità e indicatori di rischio. Rapporto 2015. ISPRA, Rapporti 233/2015.

UNISDR (2015a). Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).

UNISDR (2015b). Sendai Framework for Disaster Risk Reduction 2015 – 2030, Geneva, Switzerland, available at http://www.preventionweb.net/drr-framework/sendai-framework/ (accessed December 2017).

UNISDR (2015c). Reading the Sendai Framework for Disaster Risk Reduction 2015 – 2030, In support of the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030, Geneva, Switzerland.

UNISDR (2017a). Terminology on DRR, https://www.unisdr.org/we/inform/terminology#letter-d, (accessed October 2017).

UNISDR (2017b). Annual Report 2017. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).

UNISDR (2017c). What is DRR? Available at: https://www.unisdr.org/who-we-are/what-is-drr

UNISDR (2017d). Technical guidance for monitoring and reporting on progress in achieving the global targets of the Sendai Framework for Disaster Risk Reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).

UNISDR (2018). United Nations DesInventar Open Source Initiative - Official Website. [online] Desinventar.net. Available at: http://www.desinventar.net/whatisDISendai.html [Accessed 22 Feb. 2018].

United Nations (2005). Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters, 22 January 2005, A/CONF.206/6.

Uyttendaele, G., van der Craats, I., Schelfaut, K., Krywkow, J., Jaroslav, M. (2011). CRUE Final Report FREEMAN- Flood Resilience Enhancement and Management: a pilot study in Flanders, Germany and Italy, CRUE Funding Initiative on Flood Resilience.

Veneto Region (2017). Quadro conoscitivo PTRC, available at: http://ptrc.regione.veneto.it/quadro-conoscitivo-2009 (accesed May 2017).

Venkateswaran, K., MacClune, K., Keating, A., Szonyi, M. (2015). The PERC manual, Learning from disasters to build resilience: a simple guide to conducting a post event review, Zurich Insurance Company Ltd, Zurich, Switzerland.

Walker, G., Whittle, R., Medd, W., Watson, N., Kuhlicke, C., Steinführer, A., Dinarès, M. (2010). Risk Governance and Natural Hazards, WP 2 report, CapHaz-Net Consortium.

Wallemacq P., Below R., McLean D. (2018). UNISDR and CRED report: Economic Losses, Poverty & Disasters (1998 - 2017).

Wamsler, C. (2006). Mainstreaming risk reduction in urban planning and housing: a challenge for international aid organisations, Disasters, 2006, 30(2): 151−177.

Wamsler, C. (2008). 'Planning ahead': adapting settlements before disasters strike. In Hazards and the built environment. Ed. by Bosher, L. London: Taylor & Francis.

Wamsler, C., Brink, E. and Rivera, C. (2013). Planning for climate change in urban areas: from theory to practice, Journal of Cleaner Production 50 (2013) 68e81.

Wand, Y. and Wang, R. (1996). Anchoring data quality dimensions in ontological foundations. Communications of the ACM, 39(11), pp.86-95.

White, G. F. (1945). *Human adjustments to floods*, a geographical approach to the flood problem in the united states, Chicago, Illinois.

White, G., Kates, R. and Burton, I. (2001). Knowing better and losing even more: the use of knowledge in hazards management. *Environmental Hazards*, 3(3), pp.81-92.

Wisner, B., P. Blaikie, T. Cannon and I. Davis (2004) At Risk: Natural Hazards, People's *Vulnerability and Disasters* (2nd ed.) New York: Routledge