A master thesis of

A preliminary flash flood risk assessment for low-lying regions based on local expert knowledge: the case of the city of Emden, Northern Germany

By Jan Lennard Nolte

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Abstract Flood risk protection and its management is a broad task, which affects all societal levels. The Directive on assessment and management (2007/60/EC) of flood risk stipulates the need for reliable, yet cost effective, risk mapping. The term "preliminary flood risk assessment" is associated with the identification of areas that could potentially be flooded and therefore need greater attention and analysis. Regarding the assessment of flash floods risks, however, difficulties arise, since such phenomena are framed by the problem of ungauged basin prediction which leads to uncertainties regarding catchment response and flood occurrence. Especially in urban areas risk assessment methods, such as modelling efforts, require considerable amounts of time and resources as knowledge and data of the terrain, drainage systems and their interaction but also runoff understanding is needed. Thus, in order to obtain local risk-related knowledge in a cost-effective way, a preliminary flash flood risk assessment based on local expert knowledge was applied. The goal was to obtain spatial knowledge for the mapping of flash flood risks and to make recommendations to improve flood risk management at a local scale. Flood risk in this study is understood as a combination of the factors flash flood hazard, vulnerability (with the components exposure and sensitivity) and adaptive capacities. By the means of made experiences and perceptions of local experts and by utilizing a spatial tool, risks as well as vulnerabilities were assessed and mapped. Application of the used approach in the city of Emden, northern Germany, is described in the assessment section.

Table of Contents

List of Figures

List of Maps

List of Tables

List of Pictures

1 Introduction

Living in coastal areas in Germany is ambiguous as it brings risk and benefits at the same time. On the one hand, there are good agricultural conditions and trading opportunities pushing development and livelihood thus making coastal areas popular settlement areas. On the other hand, living in those areas is in many cases connected with a trade off or acceptance of environmental side effects such as increased exposure to multiple risk sources. This commonly includes threats posed by flooding from the sea, fluvial waters or surface waters of drainage systems which exceeded their holding capacity (IPCC 2014a). In respect to the latter two, the increased occurrence of flash floods as triggering event of flooding is of increasing concern. Recent events in Simbach am Inn, Tann and Triftern in Lower Bavaria 2016, and the projected trend towards more heavy precipitation events causing flash flood related damages revealed increasing risks originating from these phenomena (Bormann et al. 2009). Nevertheless, such risks are not being considered in many cases of common flood risk management approaches in Germany. Risk assessments as the starting point for further management processes do not include flash flood related risks in assessment procedures. (LAWA 2009) This leaves communities uncertain of information about their own risks and a gap in assessment procedures. Thus, this study attempts to close this gap by conducting a preliminary flash flood risk assessment based on local expert knowledge. For that, a flash flood risk framework is elaborated and used to collect qualitative and spatial risk-related expert knowledge on which basis the assessment is performed. The objective is 1) to identify areas that could potentially be at risk of flooding and therefore need greater attention and analysis and 2) to make recommendations to improve flood risk management at a local scale.

1.1 Increasing flash flood risk – the challenge of managing changing risks

The constant present of risks in coastal areas is usually associated with the damaging potential of storm surges and thus flooding from the sea. Exemplary in this century are the disastrous events of New Orleans (2005) or New Jersey and New York (2013), which were hit by destructives storms causing massive structural damages and causalities. Next to the risk through storm surges, flash flood hazards and the associated risk of flooding through surface waters and drainage systems exceeding their holding capacities is of increasing concern regarding coastal areas (IPCC 2014a). Rising tidal- and storm surge water levels and changes in precipitation and flow regimes will complicate drainage efforts of the hinterland (Spiekermann & Franck 2014; IPCC 2014b). One complication is associated with the reduction in duration of a natural water discharge into the sea or estuaries during low tides. A rising sea-level together with isostatic and anthropogenic processes and activities are causing subsidence of the hinterland which in turn decreases the timeframe in which a natural discharge is possible (Spiekermann & Franck 2014). In this regard, flash flood occurrences and the associated water volumes involved pose a threat to coastal communities.

Flash floods are commonly associated with "*short, high-intensity rainfall rates, mainly of convective origin that occur local*" (Borga et al. 2011, p. 1). A characteristic feature of such events are the runoff rates since they often far exceed those of other flood types. This is often due to the rapid response of the catchment area- regulated by hydraulic properties and soil moisture- which create the high risk potential of flash floods (Borga et al. 2011). Indeed, in relation to other forms of globally experienced natural disasters, flash floods rank among the highest in terms of affected people and individual fatalities (Jonkman 2005; Borga et al. 2011).

Further, predicted intensifications of the global hydrological cycle due to global warming and related climate change is likely to increase heavy precipitation on global as well as on local scale (Trenberth et al. 2003). This trend is associated with increasing flash flood related risks and potential negative consequences (IPCC 2014a). Furthermore, the increased settlement of floodplains as well as their continuous degradation because of economic usages and alteration throughout centuries results in a rising risk of flash flood damages and causalities (Howe & White 2002). Processes of industrialization and urbanization has led to other forms of land-use patterns, economic growth and the accumulation of human and physical assets which are often decoupled from environmental functions and services provided earlier by the occupied space. The transformation of former balanced ecosystems to urban space are in many cases performed by eliminating natural flood risk reducing structures like floodplains and small tributaries. By integrating them into the human built environment, former flood areas are blocked which in turn requires anthropogenic habitat alterations (e.g. drainage and sewage systems) as compensation measures. Such modifications, however, are challenged by the increased runoff rates of heavy precipitation events characteristic for flash floods.

The increasing flash flood risk is challenging common flood risk and disaster management approaches. The reason for this are the short time dimension for flash flood response and preparation and the inherent difficulties to predict flash flood generating storms and resultant flooding (Marchi et al. 2010). Nevertheless, design, implementation and maintenance of measures and processes to effectively mitigate and adapt to flood risk situations requires knowledge of the risks a system is exposed to. Problematic in this sense is that flash flood hazards develop spatio-temporal, which brings conventional rainfall monitoring and observation systems to their technical limits (Marchi et al. 2010; Anagnostou, Grecu & Anagnostou 2006). The rapid occurrence, local spatial dispersion together with the rapid response of the catchment area to heavy precipitation "*limit our ability to issue timely flood warnings*" (Borga et al. 2011, p. 1). Hence, flash floods are associated with the problem of ungauged basin prediction which leads to uncertainties. Especially since processes of runoff generation may change due to different storm severities. Understanding of flash flood generation processes is needed, yet hampered by observation difficulties. The unpredictable nature of flash flood confronts common flood risk management with ever changing risk situations making it a multifaceted task. As White, Kates & Burton I. (2001) and Menoni et al. (2012) point out, the increasing levels of risk through threatening hazardous phenomena "*has not been matched by enhanced community and environmental response so that mitigation strategies and measures have been inadequate in addressing the threat*" (Menoni et al. 2012, p. 2058). One detriment is the lack of data and information of flash flood events, especially those which can be called an extreme event. Extreme events often allow to reveal the hydrological behaviour of catchment areas that less extreme events may do not. Characterizing the response and course of an exposed system to a flash flood event can provide new and valuable insights into limiting processes for extreme flood response, the dependencies of catchment properties and their influence on flood severity. Further they may facilitate action to react to the threats posed by flooding. However, an investigation by Marchi et al. (2010) of twenty-five extreme flash floods that occurred in Europe in the last twenty years elaborated, that only half of them were properly documented. This indicates missed opportunities in this field.

1.2 Inadequate assessments of risk

The inherent difficulty to manage flash flood risk is also indicated by the exclusion of such risks in current flood risk management approaches in Germany. As part of the European Union Germany builds upon a flood risk management approach (FRM) based on the European Flood Directive (Directive 2007/60/EC).

The notion of FRM itself is following a paradigm shift in common flood management in recent years. The believe of pure risk control by the means of technical solutions to reduce flood probabilities and strengthen flood defence structures shifted towards the general consensus that traditional flood control measures are often unsuitable to prevent and cope with harmful flood events and fail in addressing the multifaceted task of their management (Restemeyer, Woltjer & van den Brink 2015; Hooijer et al. 2004; Drews 2003). As a result, more holistic risk management approaches emerged which recognize the consequences of flood hazards and promote more adaptive and integrated management systems (Bogardi & Birkmann 2004). Technical solutions such as dikes and storm surge barriers are being complemented with soft approaches (e.g. warning systems, spatial planning regulations, flood-proofing buildings). These consider options to reduce the *vulnerability* of the system exposed to different and interacting *sources* of risk (e.g. surface water, fluvial water, coastal water) their formation process and their characteristics. The focus on decreasing vulnerability developed out of the premise that threats through flooding cannot be fully prevented. The basic issue is that flood occurrence and consequences are determined by the complex interplay of the global and climate change together with site specific characteristics where flooding occurs (IPCC 2014a; Scott et al. 2013). Moreover, it becomes more difficult to predict flood probabilities and consequences which are fundamental to develop strategies to deal with risks (Pahl-Wostl 2006). By implementing more soft approaches, FRM intends to build a greater flexibility to address rising uncertainty from global change. Hereby, a more interdisciplinary collaborative learning approach with a multi scalar and multi actor management orientation is advocated. Thereby, more horizontal governance structures and a broad stakeholder participation is moving into the focus (see e.g. Mees, Driessen & Runhaar 2014; Scott et al. 2013; Pahl-Wostl 2006).

Giving this background, the shift towards FRM can be observed in the European Flood Directive, which provides a legal policy framework for European member states. It requires the development of risk maps and management plans by assessing areas with significant flood risk potential. The focus is thereby on flood probability reduction and the evaluation of consequences for the "objects of protection" human environment, cultural heritage and economic activities (LAWA 2009; Merz et al. 2010). However, the interpretation of the EU Directive for policy making are up to the individual states and commonly focus on risks by river and sea flooding (LAWA 2009; Heimerl 2014; NLWKN & Free Hanseatic City of Bremen 2012). Decision making and policy formulation for flood risk management approaches is on state level. Germany's FRM frameworks and policy interpretation indicate deficits in both aspects: to incorporate different sources of risk and to assess flood risk in a more collaborative manner. The shift towards more horizontal and collaborative approaches and the integration of flash flood risk in assessments is still subject of discussion between theorists and experts. The sudden nature, attached uncertainty and the tasks' own complexity are predominantly the reason of this discussion (UNISDR 2004).

In this respect, using local knowledge for the assessment of flash flood risk can be beneficial. Since flash flood occurrence is not fixed to a certain catchment area where the potential of model-based analysis is given (e.g. due to missing datasets). Engaging local knowledge and expertise in the assessment can promote sharing and transference of knowledge which enables different actors such as local communities, NGOs and scientists to work together, share their perception of risk, identify risk-related problems, gather and analyse information and consequently formulate and implement a shared long-term management strategy to achieve a consensus based risk situation. Such an approach would follow the track towards a more consultative interdisciplinary approach of FRM. Thereby, flash flood risk assessments would benefit from a pool of information from different actors, which themselves are characterized by their different values, goals and diverse socio-economic or political backgrounds that can enrich the process (Pahl-Wostl 2006; Peters Guarín 2008).

Local knowledge about hazardous events are normally available within a community and could provide essential information that agencies need for risk assessments and mitigation (Ferrier & Haque 2003; Peters Guarín 2008). Problematic in this sense is that such information of disaster occurrence is not collected since they are irrelevant for prevailing assessments. Nonetheless, techniques and methods of how to use local knowledge in nowadays modelling efforts and illustration of hazards, vulnerabilities and risk are existing. Participatory mapping for example can provide a mythology which aims to facilitate knowledge sharing and production between community member and can be used for risk assessments (Robinson et al. 2016). Spatial information of areas at risks, system exposure, sensibilities to hazards, and knowledge about the environment in general can be collected and analysed by the means of technologies such as GIS, mental mapping, and art and ground mapping in order to estimate risks much more effectively (Peters Guarín 2008). Most relevant data used for the assessment of flood risk- such as the reconstruction of past events and social, economic, cultural and environmental data- can be placed in a spatial context. Areas photography, cadastral map, digital terrain models and satellite images provide tools for displaying and visualizing information and provide "*the base map for indicating the spatial distribution of the data on people´s experience and perception, hazardous events, physical exposure and socioeconomic conditions*" (Peters Guarín 2008, p.4). As Merz (2011) indicates, statements concerning risk assessments are more reliable the better they correspond with observations at the specific location. Enabling local knowledge to influence flash flood risk assessments would be a step towards a more integrated, decentralized flood risk management approach which allows planning and decision making in a local context (Peters Guarín 2008). The identification and documentation of a communities own experience from previous flash flood events can assist them to build up capacities, construct scenarios and to reduce their vulnerability (Bollin et al. 2003).

1.3 Research objectives and research questions

Flash flood risks and their assessment are still in an embryonic state and are not included in common flood risk assessments in Germany. Thus, the objective of this research is to conduct a preliminary flash flood risk assessment based on expert knowledge about how flash flood risk is previewed, experienced and managed at local a level. Flash flood risk-related experience and memories of knowledgeable community members are assessed using a flash flood risk framework. Knowledgeable people refers to local experts in the field of water and disaster management and representative of community administration and public associations with field of action in flood risk management. This actor selection has been based on the assumption that such experts share a profound knowledge about local risks determining conditions since they are being confronted with them on a daily working basis. Their knowledge is perceived as a good starting point for a preliminary assessment. By focusing on these actors, this study moves away from a purely community based approach even though it could improve the outcome. Temporal limitations, data scarcity as well as the current mismatch between the indisputable rise of the threatening phenomena flash floods and responses of exposed human and environmental systems are reason for a preliminary examination and a smaller focus(White, Kates & Burton I. 2001; Kandilioti & Makropoulos 2012).

Flash flood risk in this study is understood as a combination of the factors flash flood hazard, vulnerability (with the components exposure and sensitivity) and adaptive capacities The assessment of flash flood risk reflects the identified and analyzed flash flood-related knowledge and perceptions which are used to identify the physical and behavioral factors that transform inundations at a place into a threatening event for the exposed people. By converting the analyzed factors into qualitative and spatial information, this study aims to spatial reconstruct past flash flood events, visualizing potential areas at risk of flooding, and to indicate opportunities and recommendations for FRM. Accordingly, the main research question is:

1. **To what extent can local flash flood-related knowledge add value for flash flood risk assessments and hence improve flood risk management?**

To answer these research question it requires two sub questions:

2. What role does local knowledge play in flood risk management and assessments?
3. How can local flash risk be assessed based on expert judgement?
4. How do local experts involved in flood risk management perceive flash food risk?

1.4 The case of the city of Emden

The focus of this thesis is Emden as case and place to conduct the research. This choice has several reasons. Firstly, the city is located in the north-west of the federal state of Lower Saxony, Germany at the northern rim of the mouth of the river Ems into the North Sea. This coastal city is characterized by a predominant landscape of marshland which varies regarding elevation at sea level range. Wide areas of the west side of the town have been embarked by dike systems making constant drainage effort necessary. Consequently, many natural and artificial waters can be found, both for drainage purposes and shipping (e,g, Emder Stadtgraben, Emder Wall, Treckfahrtsiel, Ems-Seitenkanal) as well as pumping stations to discharge the surplus water volumes into the North Sea. Emden therefore fits the profile of being prone to pluvial flooding in case of an extreme precipitation event. It is located at the coast, low-lying, requires drainage capacities and is subject to climate stimuli as regional climate predictions hint at more intense precipitation events in the future (Storch, Doerffer & Meinke 2009; Schneidewind U., Ihnen U. & Arnold K. et al. 2012). Evidence that flash flooding is a concern in Emden is indicated by the serve precipitation events in recent years, causing dysfunctions of the drainage system and surface flooding (Müller 2016). Exemplary here was an event in 2013 causing flooding of streets, basements, residential areas and subsequent damages to household goods due to polluted water from the wastewater sewage.

1.5 Structure of the study

In order to answer the research questions, this thesis is structured into three parts: a theoretical, methodological and an empirical part.

Chapter 2 – the theoretical framework - defines flash floods, provides an introduction into flood risk management and assessments and thereby explains the role and benefits of local knowledge in that context. Further, a risk framework is elaborated and translated into a conceptual model to assess flash flood risk based on local expert knowledge.

Chapter 3 - the methodology - proposes the approach for assessing and analyzing the local knowledge for a preliminary flash flood risk assessment. The chapter explains, how spatial and non-spatial information are collected and used as means for the analysis.

Chapter 4 – the assessment of flash flood risk - describes Emden as a case study area and further presents the result of the qualitative and spatial assessment of risk. Flood occurrences and vulnerabilities are mapped from expert based data. Further qualitative flash flood risk-related experiences and information are elected and structured in such a way that they provide a first picture of the flash flood problem and associated risk at hand.

Chapter 5 – conclusion and recommendations – critically reflects the theoretical and empirical part. It draws general conclusions from the case study and gives recommendation for flood risk management on a local scale. Further, it provides reflection of the methodology used in this study.

2 Assessing flash flood risk based on expert knowledge-towards a conceptual framework

In the following sub-chapters, the theoretical foundation of this study is being laid out. It begins with a deeper insight into the phenomena flash floods and the theory of FRM. The intention here is to create a flash flood risk assessment framework based on local expert knowledge.

2.1 Flash floods

A flash flood is associated with surface flooding that follows the foregone causative storm events in a short period of time. The term "flash" also implies a basic characteristic of these phenomena, namely a rapid response of the drainage network reaching their holding capacities within a short period of time after the onset of the precipitation event. Warning times are thus extremely short (Georgakakos 1992; Borga et al. 2011). Further, flash floods are localized phenomena since they occur in spatially small basins with response times of a few hours or less (Borga et al. 2007). Basin characteristics such as steep slopes and soil moisture or anthropogenic induced alteration of the natural drainage affect and intensify catchment response.

Especially in an urban context, flash flood occurrences are closely coupled with urbanization and development which cause drastic changes of the hydrological behavior of floods and runoff. Harmful practices such as land sealing, piping of surface waters as well as land filling influence and hamper the natural absorption and regulatory capacity of the terrain, leading to higher runoff rates and consequently to more frequent and long-lasting flood events with different effects on the exposed system. Regarding coastal cities, three causes can be identified which are conditioned by the occurrence of intense rainfall in combination with the build environment -or as Grundfest & Ripps (2000) put it, when "*too much water in too little time*" is involved:

1.) Lack of drainage infrastructure
2.) Blockage of the drainage system
3.) Flooding in low lying areas

In a coastal urban environment -unlike in environments with altitude differences where runoff characteristics are far more extreme- isolated or patchy-distributed inundations are often caused by a lack of adequate drainage capacities or a blockage of the existing drainage systems. Further, earth filling of old tributaries or wetlands withdraws the rainwater retention possibilities, which in turn leads to stagnation of rain or small flood waters in low-lying areas. Since coastal areas are more often characterized as low-lying, a larger spatial distribution of flood waters is assumed. Flash flood hazards in this study are defined as a temporal overflow of water on terrestrial areas as a result of exceptionally high amounts of rainfall, combined with anthropogenic influences on which behalf basin response occur particularly rapidly in the wake of disturbances in the natural drainage (e.g. building development, sealing, deforestation, land-use) and through topographic (e.g. slope, low-lying) and soil conditions in the catchment (Lóczy, Czigány & Pirkhoffer 2012; Norbiato et al. 2008).

2.2 The role of local knowledge in flash flood risk management and assessments

Traditionally, the reduction of flood risk has been concentrated on strategies which were purely hazard-oriented (van der Brugge, Rotmans & Loorbach 2005). Hazard-oriented refers to models and measures established by experts and authorities with the focus on technical solutions to reduce flood probabilities and strengthen flood defence structures (Meyer, Scheuer & Haase 2009). Attempts to decrease the vulnerability and thus the consequences of flooding have been of minor importance (Vis et al. 2002). Meanwhile, it is well recognized that technical solutions alone do not solve the flood problem. There has been a shift over the last decades, from "flood protection" towards a "flood risk management" paradigm which places risk mitigation and avoidance in a central position and further support knowledge sharing, public commitment and partnerships to implement collaborative risk reduction strategies at various levels (UNISDR 2005). The recognition that traditional flood engineering cannot solely focus upon the definition of a design flood event and resultant adjustments of systems that are aimed to prevent flooding in conditions of that severity, led to a change of views (Merz et al. 2010). In fact, determinant factors of flood occurrence and development and their assessment change are diverse, interdependent and vary in time (see e.g. Bronstert et al. 2007, Kruse 2010, Ott et al. 2013; Merz et al. 2014). The resultant difficulty regarding the variability of the underlying stochastic processes, respectively the problem to measure and interpret climate-flood processes are in this respect subject to natural and epistemic uncertainty (Apel et al. 2004). The believe of pure risk control, by placing the risk term in a probabilistic and decision-theoretical context, shifted toward the recognition, that the technical determination of the hazard probability and potential occurring damages do not match the wide range and variety of risk contributing factors (Kruse 2010).

The emerged paradigm of FRM in its essence is to plan and decide on the management of flood risks against the background of fundamental uncertainty. Therefore, when focusing on hazard occurrences, FRM approaches tend to incorporate a multitude of events, including those which exceed the design threshold. Additionally, various flood sources and unexpected modes of failure are being addressed (Kruse 2010). The principal statement of "*living with the risk*" in FRM indicates the social approach when handling the uncertain nature of flood occurrences and consequences, namely, that adverse impacts through hazardous events will never be totally eliminated (Pelling, M., et al. 2004). Flood risk management is therefore viewed as a society wide task by emphasizing the ability of a society to adapt, cope and recover from disturbances by flooding, and thereby reduce or even prevent their impact (Birkmann 2005). As a result, more positive, adaptive and integrated systems approaches emerged such as the notion of vulnerability, adaptive capacity and resilience (see e.g. Buckle, Mars & Smale 2000; Scott et al. 2013; Davoudi et al. 2012; Restemeyer, Woltjer & van den Brink 2015). In their essence, such concepts view flood risk reduction and management as a continuous process, action or outcome in a human system (household, group, community etc.) in order to better cope, adjust or manage changing risk situations (Smit & Wandel 2006). Flood risk management in this manner is following an ongoing circular process to constantly increase the level of protection by establishing capacities at different stages in the flood risk

management arena. Such approaches are based on consensus and collaboration since measurements to reduce the flood risk at different stages are often interlinked and have an impact on many areas and sectors of society (Müller 2010). Hence, FRM is characterized by a variety of action fields and a multi stakeholder orientation, including actor cooperation in the fields water management, disaster control, regional planning, nature protection, urban land-use planning, agriculture and forestry as well as with the population (Kruse 2010). The more interdisciplinary view on FRM also reflects the "new ethnic" of the management approach, which is advocated by theorists (see e.g. Meijerink & Dicke 2008; Pahl-Wostl 2006) but also by the United Nations who sees FRM as a joint task of authorities, communities, experts and other stakeholders to decide on consensus based plans and strategies to mitigate flood risks. The procedure of risk management comprises a variety of measures and activities which by their nature involves a multi-stakeholder approach, decentralization, institutional and organizational capacity building (strengthening), engineering, community-based strategies, land use planning and development (Wolke 2008; Müller 2010). Activities such as the provision of retention areas, flood-adapted building and use, behaviour precautions, technical flood protection and information exchange are common to FRM (Kruse 2010). Returning to flash floods with their specific short space-time scales and related uncertainties posing problems to their management; flood risk management framing flash flood forecasting, warning, emergency management and prevention are thus, by their nature, suitable to cope with the characteristics of these phenomena. (Drobot & Parker 2007; Borga et al. 2011).
Integral part of FRM is the assessment of flood risk. Flood risk assessments *"as the starting point for further risk management processes should in turn be a multifaceted activity aimed at integrating the likelihood and potential consequences of an event with subjective interpretations (perceptions) of interacting, heterogeneous actors"* (Peters Guarín 2008, p. 14). It is believed that a more collaborative approach which, among others, adopts a facet of community-based methods enable a better definition of risks from threatening phenomena and can help to identify those structures and individuals vulnerable to such threats. Building on a more collaborative risk assessment, a community is able to determine the risks they are confronted with, decide on what risk is acceptable and which measures and possibilities exist to reach this planned risk situation (Bollin & Hidajat 2006; Buckle, Mars & Smale 2000). Nevertheless, common flood risk assessments are using modern technologies and analytical skills in order to identify the areal extent of inundation and thereby enable the display of risks and vulnerabilities on which behalf management efforts are taken place (see e.g. Merz, Thieken & Gocht 2007). The determination of risk areas and subsequent decision making following the assessment are performed by a restricted number of scientists and engineers.

Acknowledging the analytical skills of modern information systems such as GIS, hydraulic and topographic analyses and detailed flooding calculation (see e.g. DWA 2015), traditional wisdom should not be diminished in the assessment, especially giving the inherent difficulty of modern technology to predict and capture flash flood occurrences. Thus, information of knowledgeable people should be a central starting point to not only supplement technology based techniques but also to create a first inventory of the risk situation. Especially in situations where model based analysis is difficult to perform, local risk information to assess the flood risk is beneficial. Clearly, local knowledge already showed benefits to technology-based solutions by incorporating people's observations, historical knowledge and believes (Peters Guarín 2008; Tran et al.; Bollin & Hidajat 2006). Generated community-based data, like those of experts and knowledgeable people who are confronted with threats through flooding on a daily working basis can be used to obtain qualitative and local spatial knowledge about experienced and expected future risks. This type of knowledge describes -according to Peters Guarín (2008)- "*action space; is innate and sustained knowledge about the land, identifies issues of immediate significance, and encodes the information about the environment in a language a region's inhabitants understands"* (p. 23).

The added value of local knowledge to scientific approaches for risk assessments has been widely recognized (Peters Guarín 2008; Wisner 2004; Bollin & Hidajat 2006; Cutter 1996; Buckle, Mars & Smale 2000). Local people are usually more sensitive to their environment and surroundings and possess an own understanding of processes during disasters and how to deal with them. The skills, capabilities and technologies of local people and actors and how they are used to encounter hazardous situations are associated as an essential input in risk management processes (Bankoff, Frerks & Hilhorst 2004). Indeed, performed studies found out that local knowledge represents a primary source of information concerning risk characteristics such as inundation depth, intensity and damages caused by past events (Rautela 2005; Mercer et al. 2007; Mavhura et al. 2013). The process of reconstructing past events by the means of using and collecting data of those who take active part in the processes of hazard prevention, coping and recovery in public institutions can provide useful information for the development of data-sets to be used in following flash flood risk assessment efforts (Mees, Driessen & Runhaar 2014).

In the case of Germany, active participatory approaches with local involvement find little support on local level (Kjellgren 2013). Also the European Flood Directive guidelines list active public involvement merely as case-dependent possibility, leaving communities often as the end-users of information (Newig et al. 2014). Hence, participatory approaches in assessing flood risks mitigates the potential for confrontation in questions regarding flood reduction strategies and management which are often purely based on scientific procedures, excluding the public from decision making. Combining both, the risk perceptions of the local knowledgeable people and findings of researches, risk assessments are enriched and complemented (Bankoff, Frerks & Hilhorst 2004). For this procedure is requires the utilization of methodologies, tools, information and parameters which are tailored to the local context and secondly acknowledge the risk factors which theoretically enable a risk identification process (technical features and systems dimensions). In this context, it is important to ensure the possibility of compatibility with the developed flood-related local knowledge and existing spatial and non-spatial data but also with not yet performed modelling efforts/scientific studies seeking to perform hazard and risk assessments.

2.3 Risk identification and assessment

In literature, the process of risk identification, assessment and resultant management activities is commonly viewed as a process, meaning a procedure in time, which is rather dynamic than static (Kruse

2010). A general strategy is primarily to establish a risk management context and criteria. The assessment of risk requires to generate knowledge of the factors defining risk, like hazard and vulnerability and components such as exposure, sensitivity and adaptive capacity. A key step therefore is the identification and consideration of indicators defining the risk factors (United Nations 2005), their assessment so as to be able to measure risks (Birkmann 2006b). Indicators can be viewed as variables, which are an operational representation of risk related attributes for instance a systems quality or characteristics (e.g. structures, economy, population). They enable interpretations of a systems susceptibility, adaptive capacity and resilience to an impact of hazardous events (Gallopín 1997; Birkmann 2006b). Equally important is the hazard identification as the step of identifying possible threats to a community and its environment on which behalf risk criteria and factors are applied. The second step, the assessment itself refers to the methodological approach used to determine the extent and nature of risk by analyzing the hazard potential and evaluating the predominant condition of social and physical vulnerabilities and components that together could potentially harm the human and environmental system exposed - so the quantification process of risk. This step refers to the use of existing and developed data and the use of hazardous scenarios by which the risk is calculated from. The risk estimation is the completing step of the assessment, which is the actual utilization of the analysis and comprises the rational of how the risk is being portrayed, perceived and judged up on. On this basis measures and processes to reduce the risk are initiated.

2.3.1 Risk factors: hazard, exposure, vulnerability and adaptive capacity

Risk assessments in the frame of FRM is subject to a variety of understandings of what factors and components should be used to define and understand risk. In this study risk is expressed by the notation:

$$\mathbf{R}\text{isk}=(\mathbf{H}\times\mathbf{V}_{(E+S)})-\mathbf{A}$$

R=Risk, H=Hazard, V=Vulnerability, E=Exposure, S= Sensitivity, A= Adaptive Capacity

In general terms, there are two primary sources for the definition of **risk** which inherently depend upon the use of hazard and vulnerability, or occurrence (probability) and consequences. Cutter et al. (2009) refers to risk as "*the likelihood of incurring harm, or the probability that some type of injury or loss would result from the hazard event*" (p.2). The United Nations Strategy for Disaster Risk Reduction (UNISDR) (2004) also views risk as the probability of harmful consequences, or expected losses, but also indicates an "*interaction between natural or human-induced hazards and vulnerable conditions*" (p.16) affecting the risk. Kron (2002) for instance views risk as the hazard (probability of occurrence), exposure (human/economic assets at the impacted location) and vulnerability (lack of resistance to damaging forces). In this research, risk is viewed as a combination of the factors hazard (H) and elements at risk reflecting the occurrence, and further of vulnerability (V) with the components of sensitivity (S) (lack of resistance), adaptive capacity (A) (potential to reduce negative consequences of risk) and exposure (E), reflecting the consequences.

Hazard

According to the UNISDR (2009), a **hazard** can be described as "*a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or health impact, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage*" (p. 17). Natural hazards such as flash floods are normally characterized by extreme atmospheric or hydrological events and are commonly accompanied by damaging consequences for the socio-economic system within it occurs. Referring to Knight (1921) definition of risk, hazard is thus the probability of occurrence of a potential damaging phenomena (ITC 2004).

When the probability turns to reality, the hazardous event is met with predominating risks and vulnerabilities, namely the consequences. If the event is on any level harmful or disruptive to the socio-economic system, the event becomes a *disaster* , especially when the abilities of the system exceed its own coping capacities by using its own resources (Lummen & Yamada 2014). Hazards and its damage potential are based on their specific location, probability, frequency, intensity, duration, areal extent, spatial desperation and temporal spacing. They can occur due to singular or sequential origin or in combination with other hazards.

Vulnerability

The notion of vulnerability as theory and as multiscale concept in disaster research is well recognized, and its broad application in fields such as system engineering (Perrow 1984), geography (Hewitt 1983) and sociology (Beck 1992), has led to a wide range of applied definitions and concepts (Menoni et al. 2012). Vulnerability is often defined as the characteristics of a system which describes its potential to be harmed by a flood event (Gouldby & Samuels 2005) or as the **sensitivity** of a system to stresses, disturbances and shocks (Turner et al. 2003; Luers 2005; IPCC 2014b). Such systems can be a community or -regarding our case- a coastal region. Smit & Wandel (2006) views the vulnerability "*of any system (at any scale) as reflective of (or a function of) the exposure and sensitivity of that system to hazardous condition and sensitivity of that system to cope, adapt or recover from the effects of those conditions*" (p. 268). The concept of vulnerability is often seen as a sub-component of risk as it holds intrinsic characteristics of a system (see e.g. Thywissen 2006 and Brikmann 2007) which are conditional for hazard-human interaction (Menoni et al. 2012)

Exposure is generally describing the degree by which an element at risk is exposed to a hazard. As part of vulnerability it can be defined as the physical assets (e.g. building stocks, cultural sites, roads), environmental assets (e.g. ecosystems, soil, nature parks), and people (households, communities, individuals) located within the hazard prone areas (Cutter 2006; Menoni et al. 2012). The extent of the hazard – e.g. its intensity, recurrence interval, time period and area of influence- determine the exposure and thus the vulnerability of an entity (Lavell et al. 2012).

An element is a component part of a system (e.g. city, community, household). **Elements at risk** therefore refers to the components of a system within a particular area which may be adversely affected by a hazard (Lummen & Yamada 2014). Commonly associated with such elements are buildings, critical infrastructure, population, livestock, public services, the environment and others that are often referred to as "assets" with an either spatial or non-spatial manifestation. Regarding this research, the interaction and relationship among the elements at risk are crucial since they define the sensitivity of the elements to be adversely affected by the hazardous event. Further, they define the exposure and the degree to which elements of risk are exposed; be it a person, structure, activity or a process that may experience negative consequences.

The **sensitivity** of a system reflects the degree to which the systems livelihood and occupancy are sensitive to exposures. It thereby describes the characteristics of the receptor (e.g. land uses, settlement locations, infrastructure etc.) which refers to the entity which may be harmed by a natural phenomenon (risk source). Such entities are environmental, economic, cultural, political and social conditioned and change over time (Smit & Wandel 2006; Graaf, van de Giesen & van de Ven 2009).

Adaptive Capacity

The notion of **adaptation** in the context of flood risk and vulnerability usually refers to "*a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity"* (Smit & Wandel 2006, p. 328). Adaptations in this study are activities and measures to reduce risks and vulnerabilities to hazards. They are being viewed as manifestations of the **adaptive capacity** of a place. For this study, adaptive capacity is defined as an outcome of the combined components: threshold capacity, coping capacity, recovery and adapting capacity which builds upon the definitions laid out by Graaf, van de Giesen & van de Ven (2009).

Threshold capacity is similar to the notion of resistance which is often used to describe the capacity of a system to reduce the probability of flooding by for instance applying technical flood protection and building precautions. It specifies the level of a probable "technical safety" from flooding.

Coping capacity represents "*the capacity of society to reduce damage in case of a disturbance that exceeds the damage threshold" (Graaf, van de Giesen & van de Ven 2009, p. 411).* Regarding FRM, coping capacities are usually associated with the presence or creation of certain structures and procedures which – in the case of a disaster- are initiated or used to reduce the damage. This implies *inter alia ad hoc* measures such as effective emergency and evacuation actions based on pre-existing plans, efficient risk communication to create awareness of possible risks among society, but also the availability of a clear organizational structure and responsibility for disaster management reasons which needs proactive planning.

Recovery capacity in this research refers to as the capacity of flooded areas to reconstruct buildings, infrastructure, and technical flood defences so as to "jump back" to the previous state before the disaster. It is closely connected to economic and financial assistance in the aftermath of an event to aid reconstructions. Adapting capacity refers to the capacity of any system to cope with, adjust to "*uncertain future developments and catastrophic, not frequently occurring disturbances*" (p. 411). The focus is on future developments and hazardous events and how they can threaten a systems future functioning. Future developments have to be seen in an uncertain context (e.g. population growth, urbanisation or climate change) and adaptations have to take place in the frame of this future context. Land use and building codes decisions for example are often seen as determinants for future vulnerabilities since they are presently being taken.

Any changes in a system enabling it to better deal with problematic exposure and sensitivities, reflect adaptive capacity. For the process of making adjustments within a system to make it less vulnerable resources are required, either to recover from, prevent or cope with hazardous events. In this respect, adaptive capacity or capacity building are linked with the way resources are available, used and managed. The process of assessing capacities in the frame of risk assessments is therefore to understand how people and communities experience and react to hazards and what strategies and resources (material, organizational) they use and develop to better prepare for, cope with and mitigate to the negative effects of hazards.

2.3.2 Translating the risk factors into elements for a preliminary flash flood risk assessment framework

Making statements about flash flood risks and opportunities of the future are closely linked to social conditions and processes influencing risk that are already present at a location before a disaster took place and can directly influence the extent of impact and damage. Likewise, other factors which do not correlate directly with hazardous situations but still effect a systems ability to respond, cope and recover from a disaster are also influential. Such pre-existing circumstances making a system vulnerable, contribute to a disasters severity, and thus impede effective disaster management and response. Understanding and investigating both, the prevalent conditions and factors by which a system and its individual components are put at risk by a hazardous event, but also simulations and scenario crafting of possible futures are key to grasp risk in disaster management (UNISDR 2005; Wisner 2004; Turner et al. 2003).

This study sets focus on the pre-existing circumstances contributing to flash flood risk and on collecting and analyzing risk determinant factors and their components. For this, the emphasis is laid on assessing local knowledge and perception on flash flood risks for a first discussion and spatial assessment of such risks. The collected information then can be further used as input for future local flood risk assessment and management efforts carried out on micro- and meso-scale by local and state authorities, technical staff and NGOs. Qualitative and spatial information reflecting the understanding and perception of a community's risk should be viewed as equally important than striving for quantitative data for flood modeling efforts or calculating the spatial extent of flood hazards and risk factors (Peters Guarín 2008).

The risk framework used in this study employs the risk factors defined in chapter 2.4. The describing risk factor components are chosen based on the performed works laid out by Lummen & Yamada (2014), Hahn, León & Hidajat (2003) and Bollin & Hidajat (2006) who performed disaster risk assessments on community and expert-based level and thus are viewed as appropriate for thus study. The risk framework consists of the factors flash flood hazard, vulnerability (with the components exposure and sensitivity) and adaptive capacities which together allow the illustration of who and what could be vulnerable or at risk

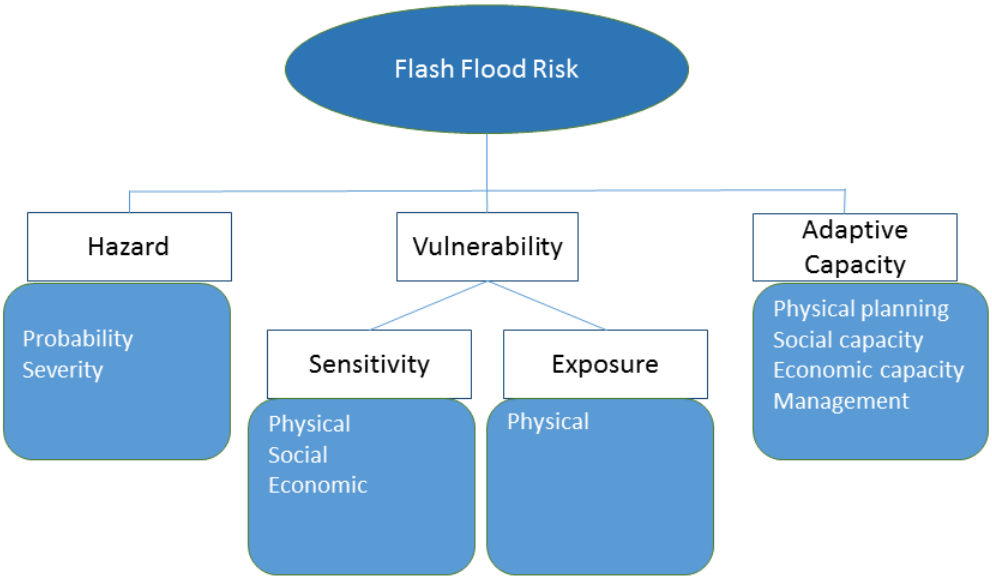


Figure 1: Flash flood risk framework; Source: (Author)

and further indicate where, why, when and how elements are at risk of flash flooding. The areal focus of the framework is thereby set at regional level (city of Emden, Germany) which will be further elaborated in the course of this study. The qualitative and spatial interpretation of flash flood risk or issues which can increase the level of risk are associated with exposures in form of inundations experienced during past events, but also missing adaptive capacities and increased sensitivities which can raise vulnerabilities of the area are under focus.

The specific local appearance of flash flood phenomena also reflects the frameworks scales of analysis and interpretation. Local knowledge and perception of experts and knowledgeable people is connected to obtaining and analyzing information at both micro- and meso-scale. This implies persons of formal and informal institution (e.g. city authorities and service provider) but also citizens which represent groups of interests (administrative and public employees, service providers, public and municipal associations). A small scale focus in this matter allows a more contextual research which might record issues which are overlooked on broader scales.

The risk framework is further translated into a conceptual model which clarifies the assessment approach of the risk factors hazard, exposure, vulnerability and adaptive capacity and their components (see Table 1.). The elaborated assessment framework presented in the following is thereby focusing on both, the collection of expert perceptions and spatial data developed by experts.

Table 1: Conceptual model of risk factors and components for flash flood risk assessment, Source: (Author)

Risk factors and components of the conceptual model for flash flood risk analysis		**Indicator and parameter used to qualitatively and spatially represent the preliminary flash flood risk based on expert judgment**	
Hazard flash flood	Flood probability and severity	Occurrence and intensity	-Identification of flash flood as a risk to the city -Experienced past events and their determining conditions -Inundation depth, areal extent and consequences of extreme flash flood events based on past events
Vulnerability	Physical exposure and physical sensitivity	Location, buildings, transportation systems, utilities areas at risk, buildings, drainage systems and sealing	-Properties within experienced flood zones: general building stock, essential facilities, high potential loss facilities, highways, railways, ports, water and wastewater, electricity, gas and oil facilities -Existence of basements -Surface elevation of the terrain/low-lying areas -Maintenance and quality of ditches and drainage/rainwater/sewer systems
	Social sensitivity	Age structure, behaviour	-Age of the residents -People's behaviour and actions
	Economic sensitivity	Businesses	-Business size
Adaptive capacities	Physical planning and engineering	Resistance to stresses, applied building codes	-Technical safety, resistance of structural/technical mitigation measures such as drainage systems etc. -Consideration of risk decreasing requirements
	Social capacity	Risk perception, public emergency response drills	-Existence of public awareness programs -Existence, tests and exercise of plans
	Economic capacity	Recovery tools and resources	-Insurance marked to transfer flash flood related damages -Resources and willingness for investments
	Management and institutional capacity	Monitoring, risk governance	-Monitoring networks: weather radar, precipitation forecasting system, food forecasting system -Established risk management/ emergency committee -Allocation of tasks and responsibilities among agencies -Established protocols for information sharing -Existence of a risk map and emergency plans -Institutional capacity building/warning skills -Barriers to adaptation

Assessment of the hazard factor

Hazard identification is normally based on historical precedents of a hazardous phenomenon which may not be given (DWA 2015) . Thus, the alternative is to express the hazards` probability as the likelihood that an event may happen in the future. In this regard it is not certain when, where and to what extent a hazard occurs, yet it is possible to identify areas where it is more likely than in other areas. For this study flash flood hazards are assessed based on the general perception of flash flood as a risk during past occurrences, but mainly by sensible areas where flooding is more likely to occur. This includes low-lying areas and flood plains, bottlenecks as well as areas where drainage systems exceed their capacities thus leading to surface flooding. The severity of a flash flood event is usually measured for a specific location applying hazard specific scales (e.g. inundation depth, flow velocities and nature and quality of carried masses) which require complex simulation efforts and data availability (DWA 2015). However, this is not intended in this study. In the frame of a preliminary assessment, a topographical analysis is applied. Inundation depth and thus the severity is assessed by reviewing local differences in height. Further, statements regarding experienced inundation depth, areal extent of flooding and their condition of occurrence are considered.

Assessment of the vulnerability factor

Vulnerability is analyzed and presented by the components physical exposure, physical sensitivity, social sensitivity and economic sensitivity. The three vulnerability components: physical, social and economic, which for some part expounds upon the definition laid out by (UNISDR 2009) are well-known criteria used in risk management. Underlying is the concept of sustainable development, which, according to the United Nations, consist of the three pillars – social, economic, and environment (United Nations 1993; Birkmann 2006a; Brikmann 2007). Environmental vulnerabilities in this study, however, have been excluded for further investigations. This is due to the assumption that flash flood events in low-lying coastal areas are not being associated with high flow velocities and thus limited contaminant transport which might endanger the environment.

The physical exposure component of vulnerability describes identified elements at risk that are perceived to be subject to the physical demands imposed by an experienced flash flood hazard, and which have been built to serve society's needs. Identifying and assessing those structures and areas exposed can offer stimuli for more detailed and individual investigations regarding building structure, how they have been maintained since construction, and what individual adaptation options might be worth thinking about to reduce flood impact.

In this study, perceived physical sensitivity are being associated with the degree of existing basements (see e.g. Menoni et al. 2012), undersized drainage systems and missing drainage concepts but also low-lying areas.

The social sensitivity is connected to age structures and socio-economic dependencies. An aging population structure is often associated with limited physical abilities to overcome a flash flood (Terti et al. 2015). In the contrary, elderly people of a community may have more knowledge of the local environmental condition and carry out flood risk reducing activities which younger people and newcomer might neglect. Information about tendencies and performance of the community in this matter might indicate missed opportunities such as awareness-raising measures and policy response.
Flooding can cause a standstill of economic production which may lead economic losses. As Davidson R. & Saha (1997) and Albala-Bertrand (1993) indicate, that the size of a productive unit is generally a good indicator for the sensitivity of a production unit. The economic sensitivity component is thus describing the economic importance of major community employer for the region.

Assessment of the adaptive capacity factor

In order to simplify the used terminology, adaptive capacity in this study comprises the factor components physical planning and engineering, social capacity, economic capacity and management and institutional capacity which are viewed to represent the outcome of the combined components: threshold capacity, coping capacity, recovery and adapting capacity presented in chapter 2.3.1.
The component physical planning and engineering is associated with structural measures which decrease the probability of exposure on any level in order to build up a certain threshold against variation so as to prevent damage. This can include present of preventive structures such as storm water retention areas, pumping stations, drainage capacities and adapted buildings that can limit or prevent an impact by a flash flood event. Expert information about capacities form the determinants for the height of the threshold. Also counting to the component are building code regulations which may decrease present and future flood risks. Exemplary here is the expertise of such fields to grant building constrains at certain risk prone areas or at least to request certain planning and design requirements for structures.

Social capacities as adaptive capacity component refers to the ability of individuals or groups to act in an informed manner in case of a flash flood event. An important factor here is the perception of risk and the priority it is given. The focus hereby should be the provision of information about risk and the inclusion of inhabitants in flood risk management to build up precautionary behaviour and awareness. In this sense, public awareness programs, emergency response training and participation in management task are viewed as beneficial to build up social capacities and decrease vulnerabilities. Information about implementation and extent of such measures are used as input for a qualitative consideration of the social capacity.

The economic capacity component refers on the one hand to risk transfer mechanisms to reduce the financial risk. In this case statements about sufficient financial resources of risk controlling institutions (e.g. drainage association and supply companies) which enable them to invest in mitigation and adaptation measures is seen as conditional to reduce the flood risk.
Perquisite to efficiently and effectively response to a flash flood event -both in the short- and long-term- are formal organized activities that are conducted either before or after a flash flood event, but with the

primary focus of improving post-flood activities (cf. Davidson R. & Saha 1997). The management component describes the emergency response and disaster control system/mechanism comprising the governance of risk which experts perceive to be in place. For this study, risk governance efforts are:

- The existence of an official qualitative monitoring network such as a weather radar and precipitation and flood forecasting models for timely warnings. Those are reflected to that determine the populations ability to undertake proper coping actions (Lindell & Perry 1991). Effective warning efforts are connected to dissemination capabilities in order to reach the population in danger (Sharif et al. 2012) as well as the quality of the warning (Vinet et al. 2012).
- The existence of flood risk maps to systematically tackling risk, and an emergency plan to reduce human losses in case of an extreme event.
- The existing of a functioning risk management/emergency committee/system to coordinate the flood response efforts.
- The existence of established communication lines to national institutions.

2.4 Conclusion

Flash flood risks are by nature difficult to manage and to assess due to the sudden nature and changing risk situations. Their local appearance requires tailor-made solutions for the identification and assessment of risk which go beyond the use of science-based knowledge to make numerical conclusions. In this research it is acknowledged that flash flood risk is perceived differently by "*those that see the flooding as a phenomenon to measure and model and those who have to deal with their effects in their everyday life* "and who in consequence developed their own abilities and capacities to process risks. (Peters Guarín 2008, p. 39). Hence, spatial and qualitative local expert knowledge (e.g. historical knowledge, experiences, observations and perceptions, etc.) is recognized as important input for flash flood risk assessment and management in this study. Local experts and knowledgeable people know best about the circumstances and changes within the location they live and work and what consequences resulted from past events and what worse can be expected if an even disastrous event occurs. Identifying and assessing flash flood risks in this study requires to view risk in a multidimensional context. Next to the more evident physical aspect of flood risk other facets that concern human dimensions are taken into account. Vulnerabilities like physical, social and economic sensitivities and exposures of elements at risk, but also the ability or inability of a system to establish capacities to respond to or manage risks are being considered.

3 Methodology

In general, efforts aiming to collect information to represent the flash flood risk of a community requires learning from the people's knowledge and perceptions. In this study the focus has been placed on Emden as a case study. Information of knowledgeable people and experts of the city have been used to receive a preliminary evaluation of the risk situation.

3.1 Case study as research methodology

As already discussed, risk is place and system specific, dynamic and dependent on contextual characteristics. Thus, in order to guarantee a true picture of risk, the context within risk is perceived is crucial. Additionally, building on the hypothesis that local knowledge is essential for addressing and assessing risk, this thesis utilizes a case study approach. Following Yin (2014) a case study approach seem appropriate when the focus of a study is to answer a "how" and "why" questions, and further, when one is trying to cover contextual conditions since they are believed to be relevant to the phenomena under study. Developing and accessing flash flood risk-related knowledge for a certain place is about "how" and "why". For instant, how can the risk-related knowledge be obtained, what factors and indicators can be used and why can they be used to reflect the local risk situation perceived by others?

Map 1:The city of Emden, Source: (City of Emden 2015)

The city of Emden (see Map 1) was chosen as the case to conduct the study since it fits the profile of being prone to flooding in case of an extreme precipitation event. Local characteristics and regional climate stimuli as well as the occurrence of serve precipitation events in the past supported that choice. The focus on performing a single case study is due to the context and location specific characteristics of flash floods. Occurrences and consequences of such events are unique for every recurrence. Flash flood risk assessments need to be tailor-made to its specific context and are thus case specific.

3.2 Methods – spatial data collection and semi-structured interviews

The method proposed for this study is to link the experts' knowledge and local citizens' knowledge with flash flood hazard risk by using mapping and semi-structured interviews enabling the collection of qualitative and spatial data for risk and vulnerability identification purposes. A more detailed outline of this methods and tools are given in this course of this chapter. Giving the inherent difficulty to measure and capture flash flood risk by the means of modern technologies and due to limited qualitative and recorded data availability, community disaster and risk management schemes can be enhanced from collected information about risk factors and characteristics originating form made experiences and perceptions. Further, external actors are provided with a more comprehensive view upon the local risk situation which can be used for GIS-based risk assessments conducted on state level.

By utilizing a participatory approach in form of mapping, the researcher aims to capture a representation of people's knowledge as spatial information which can be used to analyze risks but also opportunities for action priorities in the flood risk management arena and further help communities in risk communication processes.

The usage of methodologies which on the one hand collects the unfiltered information of experts and knowledgeable people separately was considered as appropriate since the chances that authorities and experts who might work in the same field, yet have different perceptions and opinions about risk related topics, did not get manipulated thus ensuring that the research responded to the experience and perceptions of not only those in power. Further, by incorporating knowledge of experts and people with different backgrounds a rich picture reflecting the local context, working procedures and everyday interactions was provided.

Before the data collection took place, secondary and primary data were collected. This included a literature research. The rationale behind this was to learn from others about the topics of risk, flash flood and local knowledge in general and how to craft a framework appropriate for the context and scope of this study. The processes of data collection, analysis, interpretation and illustration have been structured according to the framework. Additionally, spatial data was obtained from open sources. Topographic data, natural features (rivers and channels) and land use data were used during the process of risk information collection and illustration. Also a high resolution base map of Emden was made available by the cadastral office Aurich and further printed and used as the key spatial layer on which basis other types of data would be linked regarding the illustration of risks and vulnerabilities which follow the conceptual model presented in this study.

Further, policy documents and news articles were reviewed and analyzed, both for background information and to place the management of flood risk in a formal local context. Insight into national FRM policy and strategies was obtained from publications of the "federal working group water" which gives recommendations for the implementation of FRM approaches in Germany. Also, state specific FRM strategies and national strategies of how to adapt to climate change have been analyzed. To obtain an understanding of how to assess flood risks in practice, DWA (German Association for Water Economy, Waste Water and Waste) publications were used. Such publications are commonly setting the norm for practically oriented applications and indicate the state of the art of FRM in Germany. Finally, in order to be able to contextualize the case, literature about local topographic, soil and water management conditions were revived. Important here was to obtain an understanding about the drainage situation, how it functions and who is responsible.

Semi-structured interviews and mapping

As means for data collection purposes this study utilized semi-structured interviews in combination with mapping for obtaining spatial information of flash flood risk-related knowledge.

Semi-structured interviews offer *"a degree of predetermined order but still ensures flexibility in the way issues are addressed by the informant" (Dunn 2005, p. 80).* It is a method used to collect primary data by taking advantage of a defined structure and simultaneously being flexible to follow interesting topics the interviewee touches upon. All interviews performed were based on a tailor-made interview guide adjusted to the theoretical context and knowledge competence of the people questioned.

In total 8 Interviews were conducted to collect the data from which 5 were used to collect local qualitative and spatial data. The other three were external interviews to collect information about FRM in general. All interviews lasted approximately an hour and a half and took place in the respective working environment of the people questioned. At the beginning, standardized questions regarding past occurrences, courses and frequencies of past flash flood events were asked as well as questions regarding the perceptions of flash flood risk in general. The second part of the interview – this concerned those interviews which intended the collection of spatial information- involved the mapping procedure. A detailed A1 black and white copy showing the city of Emden was used as ground layer in which the interview partners visualized and explained information regarding past flood occurrences, exposures, vulnerabilities and adaptive capacities in different colors (see Map 2). The third part of the interview was used to collect qualitative information about risk governance and management issues, barriers and possible solutions to better cope and adjust to potential flash flood risk situations.

Map 2: Mapping tool for data collection proposes, Source: (Author)

The persons interviewed were chosen on the basis of their competences and their function in FRM processes and field of action. Actors in the field of water management, hazard prevention and emergency response have been viewed as important interview partner due to their influential activities in flood coping, provision and prevention. This included the local manager of the Construction and Disposal Company (BEE) and the head of the in-house operation Department Disposal and Urban Drainage who are in charge of the waste and rainwater sewage. Also, a member of the Drainage Association Emden was interviewed who is responsible for large parts of the inland drainage in Emden. as well as the director and his deputy in the field Civil Protection and Disaster Response who run the operative emergency response in Emden.

Representative of groups of interest as well as city authorities working in the sectors of water, climate and environment have been chosen as interview partners as well. City authorities represent the formal instance regarding legal requirements for flood adaptation and response. Therefore, representative of the Professional Service Environment; Climate Protection Management; and Water Maintenance & Local Lower Water Authority Emden were interviewed. Regarding community representative which are perceived to embody public response and behavior towards flood risks, an interview with the Representative Farmers was conducted.

Additionally, 3 external interviews were performed. One with the Flood Forecasting Center of Lower Saxony to get an understanding whether and how flash floods can be predicted and what kind of warning times exist. The second interview was with the flood risk management department of the senator of the Environment, Development and Traffic which among others was involved in the KLAS (Climate adaptation strategies) project which aimed to develop long-term strategies against extreme weather events.

The purpose of this interview was to get an insight into the topic heavy precipitation evets and how other cities deal with the problem. The third interview was performed with the Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency (NLWKN) in Verden who are responsible for the assessment and creation of flood risk maps for Lower Saxony. This interview served to get an insight into the current flood risk assessment methodology.

Table 2: Interviewees

Interviewee	Organization	Function	Date
Interview 1	*Senator for the Environment, Development and Traffic Bremen*	*Flood Risk Management*	*22.08.2015*
Interviewee 2	*NLWKN Verden*	*Project group Flood Risk Management Directive*	*22.08.2015*
Interviewees 3	*City of Emden*	*Environmental services, climate protection, water maintenance*	*24.08.2016*
Interviewees 4	*Construction and Disposal Company Emden Department Disposal & Urban Drainage (BEE)*	*General management, disposal and urban drainage*	*25.08.2016.*
Interviewees 5	*Fire department Emden*	*Civil Protection and Disaster Response*	*25.08.2016*
Interviewee 6	*Drainage Association Emden (DAE)*	*Territory water engineer*	*07.09.2016*
Interviewee 7	*Representative Farmers Emden*	*Farmer*	*07.09.2016*
Interviewee 8	*NLWKN Hildesheim*	*Flood Forecasting Centre*	*09.09.2016*

3.3 Data analysis and interpretation

Data analysis and interpretation as means to turn the collected qualitative and spatial data into credible evidence is described in the following. The spatial information on the base maps have been analyzed and presented by using a GIS program. The program provides different techniques and processing tools to overlay various datasets and to extract, analyses, manipulate, understand and present spatial data. Various scholars have used GIS as platform for the collection and integration of local generated spatial referenced data for planning and decision making proposes (Quan et al. 2001). In this research the software ArcMap 10.3 was used for the creation of spatial data to describe and explain the systems experienced physical exposures and vulnerabilities. By using the standard geoprocessing tools and basic features such as points, vectors and polygons of the program, a map delineating flood-risks and vulnerabilities from flood-safe areas was created. For this, the local spatial information on the base maps was transferred and merged with other spatial data (topographic, land-use) for obtaining new combination of information that help to communicate, visualize and interpret flash flood risk.

According to Miles & Huberman (1994) qualitative data analysis includes "*data reaction, data display, and conclusion drawing or verification*" (p 10-11). In this regard, an inductive approach has been applied to analyze the obtained qualitative data of the performed semi-structured interviews. Here, an inductive analysis refers to an approach that uses "*detailed readings of raw data in order to derive concepts, themes, or a model through interpretations made from the raw da by an evaluator or researcher*" (Thomas 2006,p. 238). The general advantage of such an approach is that it allows research findings to emerge from the significant themes in the collected data material, without restrains imposed by structured methodologies. As a mean to condense the raw data into a brief format, the interviews were transcribed (and carefully read to identify themes, categories and meaning which were viewed to fit with contents of the theoretical framework. A coding framework was further developed and the transcripts coded. Codes applied comprised identified text segments that contain meaningful information about flash flood risk related topics. Examples of used codes are "perceived drainage problem", "experienced inundation areas/locations", "location description" and so forth (for a detailed list see Appendix 2). Performed coding enabled the analysis of the interview segments on a particular theme, here the perception and judgment of flash flood risks and performances in FRM.

4 Assessing flash flood risk in the city of Emden

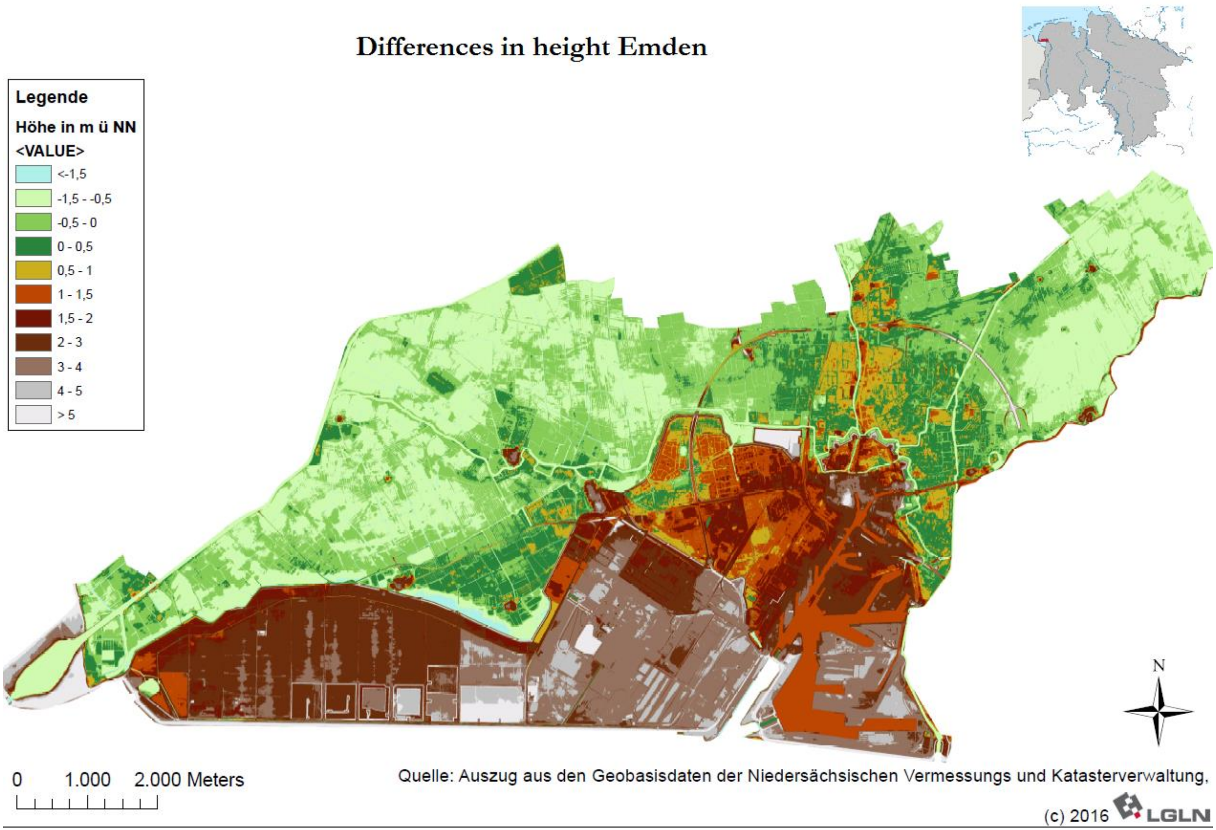
4.1 Introduction of the case

In the following sub-chapter, the area under investigation together with essential system characteristics is presented.

4.1.1 Location

The city of Emden is located in the north-west of the federal state of Lower Saxony, Germany at the northern rim of the mouth of the river Ems into the North Sea. It is a coastal port city characterized by a predominant landscape of marshland which varies concerning elevation at sea level range (see Map 3). Wide areas of the west and east side of the town (Wybelsume, Larreller Polder) have faced hydraulic fillings for land reclamation purposes or were washed over by dredged material. The used material elevated the area but are still subject to constant sagging and subsidence (Sindwoski et al. 1969). A dike system was created to protect the area from flooding by the Dollart (bay of the Ems estuary) and the river Ems. Both waters also mark the southern and western city boundary. The headland "Knock" marks the most southeastern point of Emden.

The unique location at the Dollart and the river Ems also explain the local geological subsoils in Emden, which are determined by marsh landscapes. Embankment and fillings processes led to fertile areas for

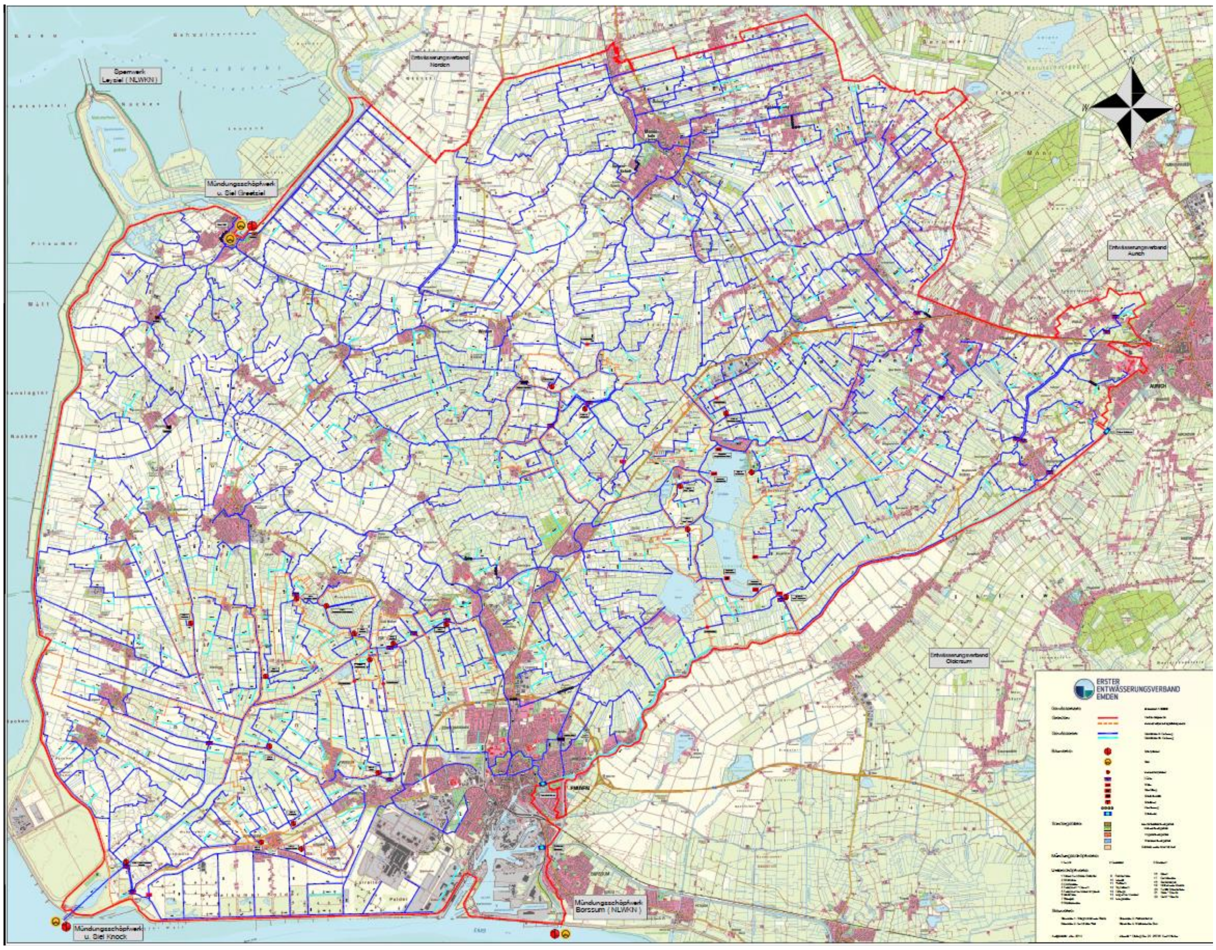


Map 3: Altitudes differences in Emden; Source: (LGLN 2016)

agricultural use which make up 61% of the land use in Emden. Generally, except to the south, the city is surrounded by agricultural areas (City of Emden 2015).

Marshlands cover almost the whole city, except to some eastern urban areas (Uphusen/Marienwehr, Borssum, Widelswher and Petkum) where other soil types were socialized. The prevailing marshlands are a combination of old and young marshlands. The latter ones can be classified into "Kalkmarsch" and "Kleimarsch". Both types can be found in areas which have been embarked in the recent centuries, mostly in the western part of the city. This soil types are normally low-lying, feature high groundwater levels and consist of a loose and stable soil structure with a high water holding capacity. Older marshlands can be found in the northern and eastern part of the city with some distance to the coast. Such areas are often under the base height level (NN) due to soil formation processes. A process which younger marshlands still face (Sindwoski et al. 1969).

The circumstances that Emden is a low-lying and embarked city makes constant drainage effort necessary. According to the DAE, one speaks of the "bathtub-effect": to the south and west -called by locals "the golden hoop" - the city is embarked by a sea dike, but also through a "high channel", the Ems-Jade-Chanel, which is generally higher than the surrounding area and is framing the city from the east. Further in the north at Moorhusen, Munkebow and others, the naturally more elevated "geest" landscape begins, which completes the bathtub. Consequently, many natural as well as artificial waters can be found, both



Map 4: Hydrological map, Source: (Water Drainage Association Emden)

for drainage purposes and shipping as well as pumping stations to discharge the surplus water volumes into the North Sea (see Map 3).

There are about 50.000 people who live in the city. Emden was founded in the eighth century as a trading hub with its sea port and inland trading routes. Back then, the city developed to the largest city of the region. (City of Emden 2015).

4.1.2 Drainage situation

Tasks related to the drainage of waters in Emden is performed by three organizations. One is the BEE and the other two are the Drainage Association Emden (DAE) and the Drainage Association Oldersum (DAO). Unlike the BEE, which is responsible for the city's decoupled rainwater and wastewater system, the two drainage associations carry out large parts of the inland drainage in East Friesland. By the means of a complex drainage system comprising hundreds of kilometers of drainage ditches, channels, pumping stations and sluices such associations control and maintain a proper dewatering through the dike line.

The territory of Emden is thereby divided. The main drains of the territory are controlled by the DAE whose boarders meet those of the DAO flowing the Borßumer Kanal inland till it crosses the Ems-Jade-Channel. The boarder then follows the Ems-Jade-Channel up to the city of Aurich. Generally speaking, both drainage associations run different water levels in their system. The DAE ensures a level of -1,27 m in summer and -1,40 m in the winter periods. Further, they maintain additional pumping stations which are placed along the "Knockser Tief", the main artery of the southern drainage system that comprises Emden up to the Große Meer. Such pumping station ensure water levels between – 2,50 m up to -2,80 m since the areas are predominant low-lying below sea level. The surplus of water of such areas, which are predominantly agricultural areas, but the major proportion of the urban discharge, is being drained through the "Knockser Tief" and the pumping station/sluice Knock which is able to discharge 60.000 l/s at its peak and guarantees the drainage of 35,000 ha land. (Erster Entwässerungsverband Emden 2016)

The DAO for their part is responsible for the drainage in the eastern parts of the town and is running a water level of -0,90 m which is somewhat higher than those of the DAE. Water of the eastern areas of Emden are being discharged primarily through the Ems-Seitenkanal and then by the pumping station/sluice Bursum and the sluices in Petkum and Oldersum. (Entwäserungsverband Oldersum 2016)
The different water levels of the drainage associations enable a turnover of water if needed. Nevertheless, according to the DAE, this possibility only exists for the DAO to discharge water volume to the system of the DEA with its lower water levels.

According to the BEE its rainwater system is also linked to those of the DEA and DEO, as the collected surface waters are being discharged into the receiving steams often held by the drainage associations. The water volumes are being drained to the moats and deeps which discharge to the existing sluices or pumping stations. Further, waters of some areas can be directly drained through non-return flaps into the harbor of Emden. It is thus that Emden's rainwater system is using short ways to discharge the amounts of incoming rainfall. The physical dimension of the rainwater system has been set on the basis of an average rainfall measured over 15 min by about 80 l/(s x ha) with an annual (in some areas also a frequency of 5 years) impoundment frequency. Pipework in Emden need to have a cover of 0,90 m between street level and implemented pipe. The average street level lies between 0 m NN up to 0,30 m NN. Given the water level of -1,27 m (in summer), a difference of about 1,27 m between water and street level prevail. Having a cover of 0,90 m and a common rain pipe of 3 m diameter, situations in which the pipe's sole is in or under the water level is a common thing in Emden. Hence, rainwater pipes generally have a permanent water level over the year.

Since Emden soil conditions are subject to sagging processes, prevailing building and pipe systems are being supported by piles or concrete beams which remain covered with water.

4.1.3 Flood risk management approach- formal actors and responsibilities

In the Water Recourse Act (2010) the national state distributes the tasks of flood protection and its management by law to the different federal states and their ministries, which are required to assess the flood risk in the frame European Flood Directive (Directive 2007/60/EC). In Lower Saxony, the NLWKN is formally in charge to implement the directive. Central aim is to assess and manage flood risks to reduce their potential consequences on objects of protection: human health, the environment, cultural heritage and economy. For this the FRM approach is based on three steps. Step one includes the identification of areas and waters with a potential risk of flooding which are determined by experienced past river flood events and the presence of mentioned objects of protections in affected areas. The assessments are performed on river basin level. Coastal areas -such as the city of Emden- are being considered separately since threats of storm surges are being presumed. The second step includes the development of frequent, medium and rare events indicating areal extent and inundation depth of flooding. Further, potential consequences on objects of protection are considered. Maps are primary used to judge flood risks and to derive flood protection and precaution measurements. The third steps include the development of flood risk management plans for the development of measures by which the public and authorities are able to encounter threats of flooding. According to § 1 sentence 1 No. 20 of the regulation regarding the responsibilities in the sector of water laws (ZustVO-Wasser), the NLWKN is formally in charge to develop such plans. The operative task flood protection however is placed at local and regional level. Thus the NLWKN request local actors and public institutions with fields of action in FRM processes to participate in the preparation of FRM-plans by defining their activities to the NLWKN which in turn creates an inventory of planed, in implementation and performed measurements (NLWKN 2016; NLWKN & Free Hanseatic City of Bremen 2012; NLWKN 2015). The actors which – according to the NLWKN- take active participation in these processes are shown in Figure 6.

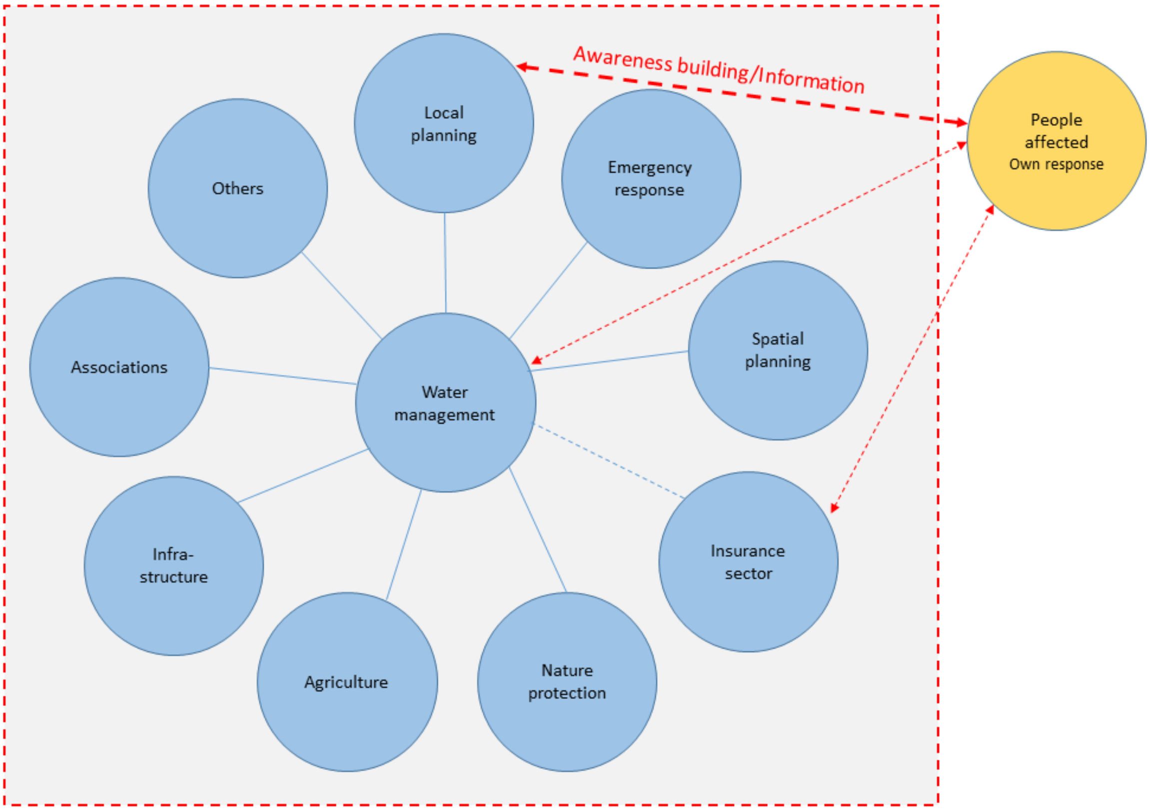


Figure 2: Actors in FRM processes in Lower Saxony, Source: (NLWKN 2016)

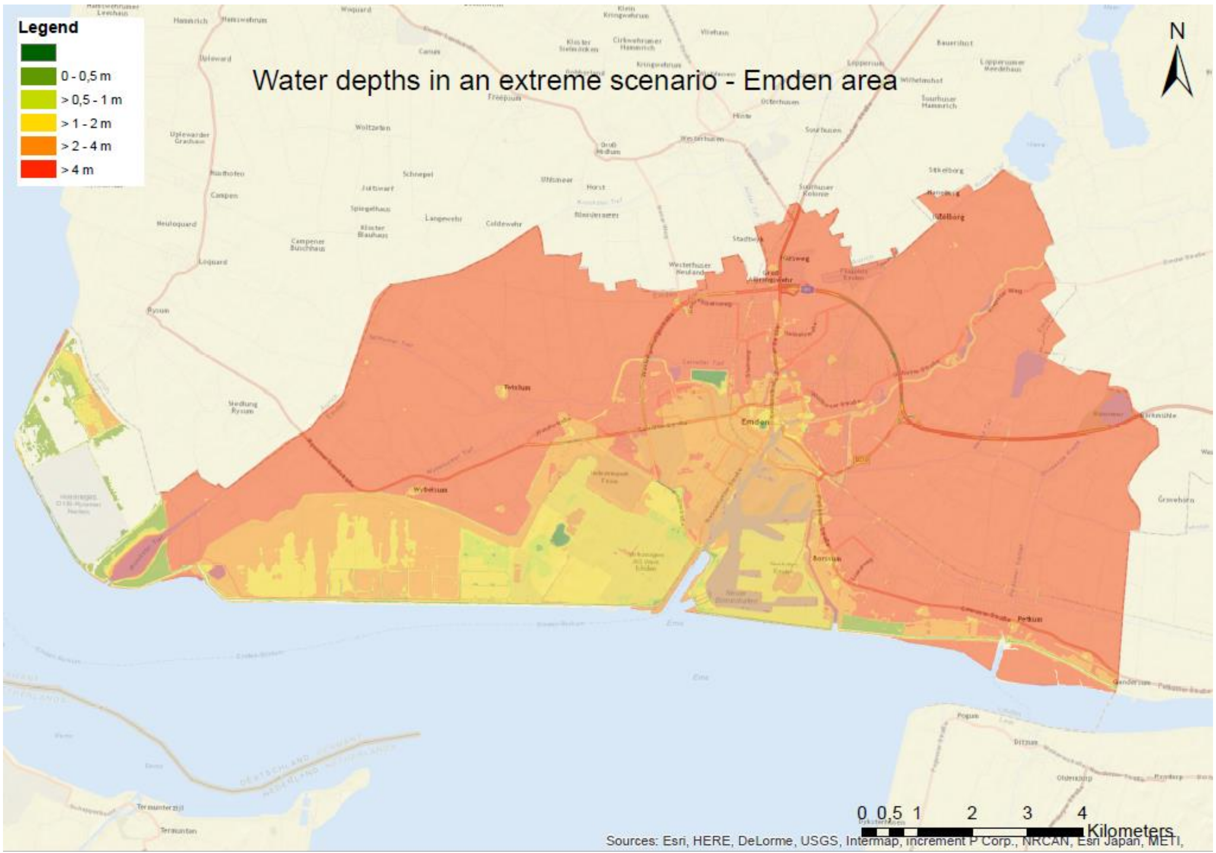
Regarding Emden, main actors taking part in FRM and who are also relevant for the local operational flood protection are the local civil protection and disaster response services (BZK), Deichacht Krummhörn, an organisation responsible for maintaining the sea dyke, water management authorities, the city of Emden as well as various service provider. Since risks of flooding are mainly associated with threats through storm surges and possible dam collapses, flood protection measures are primarily placed on technical measures such as on strengthening the sea dyke line and increasing pumping station capacities. But also new flood protection concepts, planning games and disaster control plans are being elaborated (NLWKN 2015).

4.2 Hazard identification – assessing flash flood probability and severity from an expert based perspective

The identification of flash flood hazards posing a risk to Emden as well as the experienced occurrence and intensity of flash floods in the urban context are presented in the following. Flood inundation areas and conditions leading to flood occurrences have been identified, described and spatially visualized on a base map by using a GIS tool. Marked spatial information provided by the mapping procedure and qualitative statements of the interviewee have been used as input. A detailed listing of perceived locations prone to flooding and statements of persons interviewed are presented in the appendix 1, Table 3.

4.2.1 Identification of flash flood hazard as a risk to the city

Flooding in Emden is normally associated with flooding from the sea or the Dollart. Flood risk maps of the area illustrate different flood probability scenarios to identify areas at risk. The most severe scenario, in which a dike break is assumed, affect nearly 100% of the residential zones and inundate the city up to >5 m due to the predominant low-lying areas (see Map 5.). Threats and problems through sea flooding is thus well-known.



Map 5: Water depth in an extreme scenario -Emden area; Source: (Author, Data: NLWKN)

Flash floods and its perception as a problem in Emden has received more attention in recent years, especially since 2013, where a heavy precipitation event caused drainage problems in the urban areas which led to flooding affecting homes and infrastructure.

> "*We have experienced various heavy precipitation events in recent years […] they are becoming more intensive, more powerful. It can be said, such phenomena do occur more often and flooding can be observed more often*. […] *Most of them occurred when we experienced much rain in a short time. I have been living in Emden for 18 years now. Every now and then we experience such events. Maybe two years we have nothing, but then suddenly three events in one year. We are aware of our problems*."

says the representative of the fire department. Nevertheless, flash floods are not yet perceived as a common problem: The city views that "*we had some stronger rainfalls. But I would not call them heavy y precipitation events – however to define those-. It is not a general problem. Some districts had problems, every two to three years*." In the contrary, regarding the rural areas of Emden, flash flood problems are perceived slightly different:

"*we are very close to the pumping station Knock. And normally, for us farmers, when we experience heavy rainfalls, water is being discharged very quickly. The flash flood situation does not really address us. It might be that fields are partially flooded, but that is not really a problem and after 2-3 days everything is fine again*"

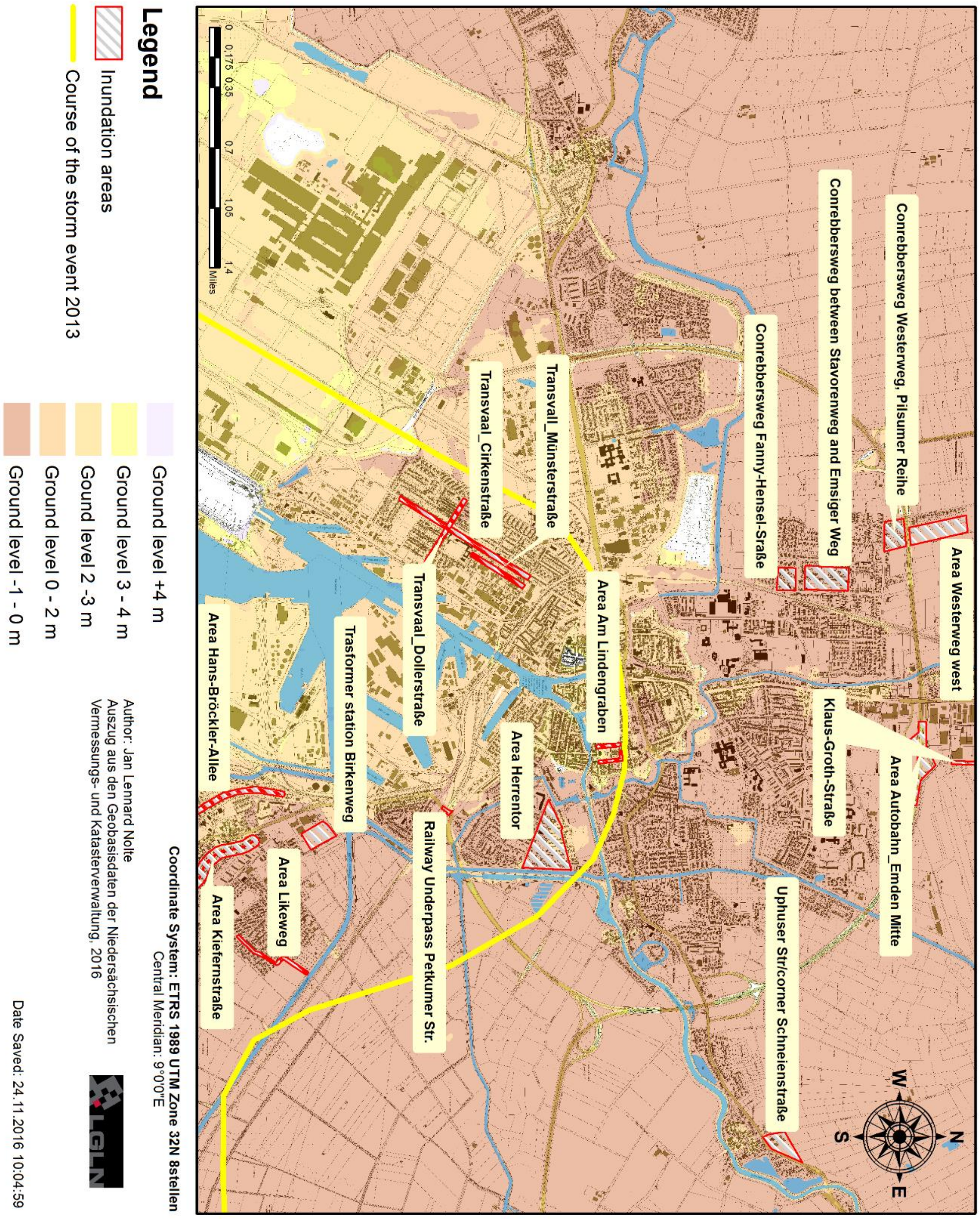
In the next chapter, a reconstruction of past perceived and experienced flash flood occurrences have been performed.

4.2.2 Reconstructing past flash flood events – flood occurrences, determining conditions and intensity

According to the interviewed local expert, a significant event on which behalf water management authorities started to pay attention concerning the flash flood issue was a heavy precipitation event in August 2013. The described course of the thunder cell is visible in Map 6. According to the BEE water volumes of more than 50 l/s were measured which caused flooding of streets, underpasses, basements and living space. The event occurred so local that the drainage associations did not notice the event in their system and were unable to take actions. The BEE on the other hand registered overfilled rainwater sewages where flooding occurred. In the consequence streets were flooded at disadvantageously locations lasting for about 20 up to 45 minutes. Further, the accumulated waters on the streets entered the wastewater sewage system and caused backwaters which mainly led to flooding of unsecured basements. Likewise, the event of 2013, other minor events caused spot flooding. However, detailed information about the development and the severity of such events could be obtained. Map 5 represents the accumulated experienced flood occurrence marked or mentioned by the interviewees.

According to the BEE, flood occurrence due to flash floods in Emden seems to have several determining condition which are more frequently interlinked. Flood occurrence which reflects the probability of flooding is associated with slow water discharge due to undersized and/or blocked pipework and resultant waters escaping the rainwater sewage as experienced in Borssum and Am Lindengraben. A causal effect is that water accumulates on the streets and enters the wastewater sewage systems which is not designed for such water surpluses. The consequences are that polluted and damaging backwaters entering houses with water connections beneath street level. Sagging and subsidence processes leading to different height relations in the sewage system and thus to bottlenecks are also cause of flooding (e.g. Klaus-Groth-Straße). Further, the extent of escaping rainwater from the sewage has to be linked to its potential distance to receiving waters (e.g. Harsweg) as well as predominant water levels in the receiving deeps. Pre-pumping at the Knock for example could have secured lower water levels and more holding capacities. Nevertheless, according to the fire department "*the DAE did not notice the occurred water volumes, since it did not rain in any other area. Consequently, they were not able react on any warning signal by for example providing more retention volumes through pumping*".

Also a conditioning factor determining flood occurrences are potential connections between occurred flooding and predominant height relations. As visualized in Map 6, flooding occurred more in low-lying areas such as in Conrebbersweg, Harsweg, Barenburg, Wolthusen and partly Borssum. However, a generalization that low-lying areas in Emden are generally more prone to flooding is misleading. This for



Map 6 Perceived extent of flooding due to heavy precipitation events, Source: (Author)

example is illustrated by occurrences in Transvaal where flood occurrences are mainly linked to filled up and blocked drainage ditches where a regulated runoff was not possible. Further, some town districts have not yet experienced and extreme event by which areas of flooding can be identified.

Picture 1: Flooded railway underpass, Source: (BEE)

The severity of flash floods reflecting the intensity of past events in regard to inundation depth and areal extent can be viewed as "less serious". According to the BEE, inundation depths on surface level were within kerb height range and, in most cases, the areal extent flooding was limited to single streets or within the range of overflowed ditches and deeps. Rarely, greater areal inundation happened due to lowered kerbs in flooded streets. In that case, prevailing slopes towards house fronts often led to flooding of living space with minor water depths. However, houses with basements often experienced basements flooding with greater flood levels. In general, the low inundation depths have been connected to the prevailing low-lying but even area and the good drainage situation. According to the BEE and the city of Emden, flooding would always be spatially distributed over the area with lower inundation depth.

4.2.3 Discussion

In general, the perception of flash flood as a risk for the city of Emden varies concerning the threat it poses. Consistent is, that no extreme event experienced represented a real threat to human life, yet structural damages were caused. All parties questioned expressed that they experience an increasing flash flood risk potential due to more and intense precipitation events in their region. In this regard, a connection to global and natural climate change and the influence on the water cycle is difficult to perform, yet could explain the increasing trend. Further flash flood occurrences and documentation of flooding showed, that drainage failure and the prevailing low-lying terrain support the occurrence of flooding. Especially the convergence of such and other conditions elevate the flood risk. The ability of the system to process the surplus of water exceeded its own coping capacities which led to flooding. In this regard, building up the capacities, especially those of the drainage system is recommended.

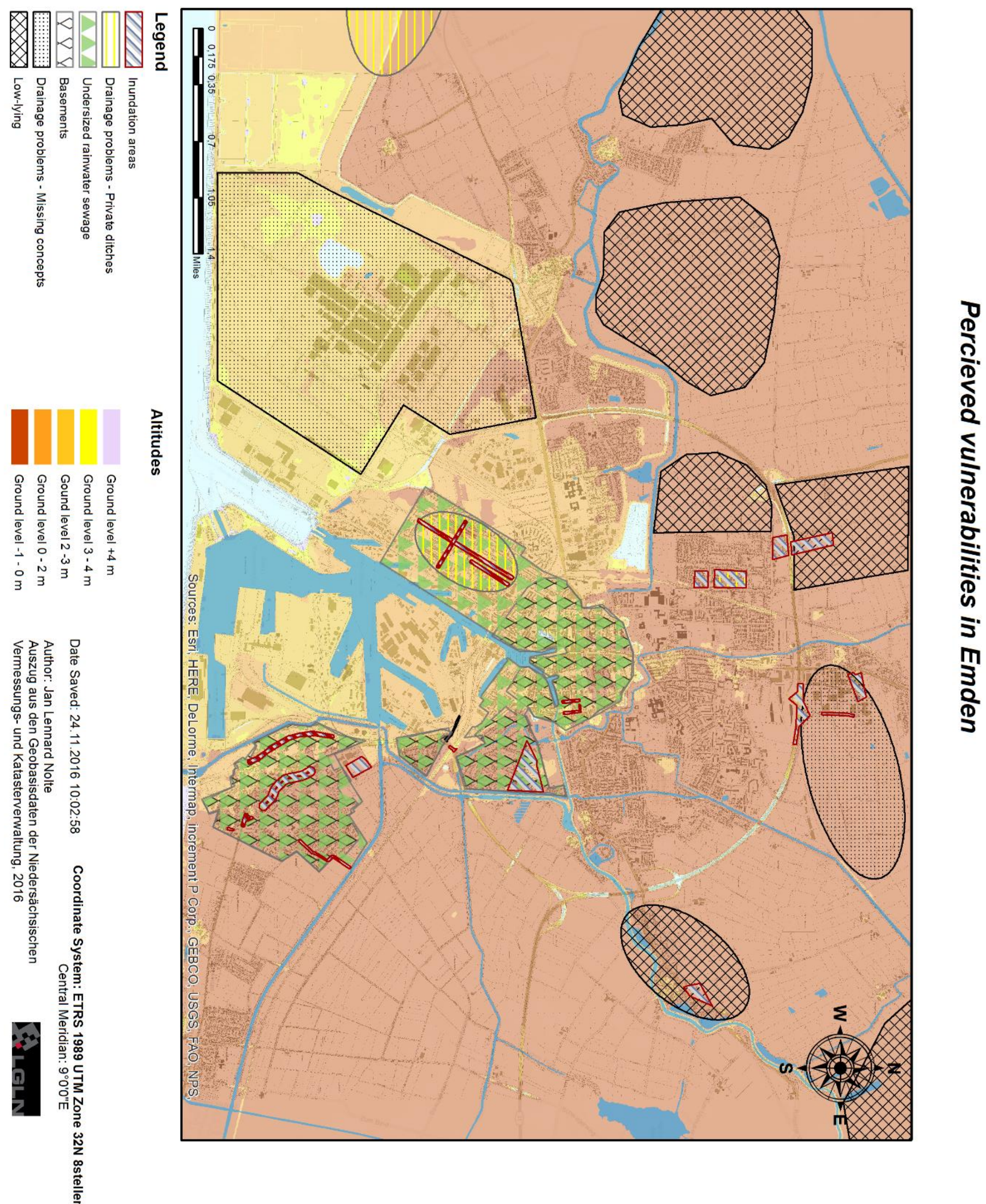
At this stage, the occurrence of extreme events in Emden can be reduced to one event in 2013. Hence, it is event questionable to call the event 2013 an extreme event since historical records to enable comparison are missing. Moreover, it is difficult to make statements about the probability of occurrence and the severity, meaning the recurrence interval of such events and potential areal inundation. To assess future flash flood risks, working with probability scenario is recommended, which should consider precipitation loads and time series comparable or higher than those experienced 2013.

4.3 Vulnerabilities to flash floods from an expert based perspective

Flood vulnerabilities of Emden are subject of the following chapter. Results are presented both by qualitative statements collected during the interview and spatial information (see Map 7). A detailed listing of perceived vulnerabilities to flooding and statements of persons interviewed are presented in the Appendix 1, Table 4.

4.3.1 Mapping perceived physical exposure and physical sensitivities

Physical exposure to inundation, meaning here the identified elements at risk that were perceived to be subject to the physical demands imposed by experienced flash flood events, occurred in the identified "inundation areas" visualized in both Map 6 and 7. The collected spatial and qualitative data showed that the town districts of Borssum, Transvaal and Conrebbersweg stick out, but also parts of Harsweg and Herrentor were exposed to flash flood events. According to the BEE, urban structures affected were primary roads with an average inundation height of 0,04-0,05 m, normally within the kerb-hight. Especially the street infrastructure of Borssum and Herrentor was prone to flooding. A critical point which has been experienced higher water levels is the railway underpass Petkumer street between Herrentor and Friesland as well as the trough section Am Tonnenhof. Both are low-lying and viewed as essential road connection by the interviewee. Also the Autobahn (A31) and the transformer station in Borssum -both highly critical infrastructure facility- were exposed regarding the fire department. Concerning exposed residential buildings, Transvall, Conrebbersweg, Herrentor, and partly Borssum has been pointed out by the people questioned. Basement flooding occurred mainly in older parts of Emden, namely in Herrentor, some in the inner city, Borssum and Friesland. In Harsweg, streets were exposed up to 0,25 m. Many businesses and shops can be found there making that areas quite sensible.



Map 7: Perceived vulnerabilities in Emden, Source: (Author)

Picture 2: Blocked ditch (l) and blocked bank (r) in Emden, Source: (DEA)

The city of Emden is confronted with a couple of issues which can increase the potential of flooding due to physical sensitivities (see Map 7). The physical sensitivity in this study has been associated with characteristics and conditions which make the systems livelihood and occupancy more sensitive to exposures. In this regard, one main issue is related to the drainage system, whose condition is determined by interactions of various factors. The first one, which is also highlighted by all people questioned, is to secure a regular cleaning of all flow regulatory water bodies independent from their categories. Nevertheless, regarding category 3 water bodies (private owned water bodies) all respondents emphasized that ditches are being filled up and that the formal obligation of cleaning are in many cases not being followed.

> *"I think that people partially do not clean their ditches properly. Especially in Conrebbersweg I experienced that a lot of people filled up their ditches. And then they start to complain "we are drowning". Conrebbersweg is the major crises area with the most drainage related problems*" says a city representative.

According to the fire department "*one can see it more frequently that people drive piles into the ditches to fill them up in order to expand their backyard backwards*".

> From the perspective of the DAE the "*main problem are water bodies category 3, which are privately owned by landlords or others -like the city of Emden-. It is often difficult to clean such water bodies since they are often placed behind properties and people grow trees and bushed there which makes the accessibility for equipment difficult and thus the cleaning*".

Also contributing to the problem are pipework's, which people implemented to replace ditches behind properties. Both the BEE and the fire department indicate that "*an open ditch is always more effective than any pipe*".

> The DAE refers to this situation as followed: "*One places a 300er pipe, the other downsized to a 200er piper, the next to a 100er and the last adds a simple drainage pipe adjusted with some tape. This might work in 90% of the cases but when more rain is coming, the whole system collapses".*

Autumn leaves which can block drainage ways but also winter frost which leads to less water absorbency of the soil and thus higher water runoff situations also alleviate the sensitivity of flooding.

Basements and underground parking spaces are also sensitive to flooding and can be found in older parts of the city (see Map 7). According to the BEE and the fire department, houses with basements are only those which are older since new developed housings are built without basements. New developed areas are primarily those to the north and west surrounding the inner city.

Another factor which contributes to the sensitivity of flooding are undersized rainwater drainage systems, especially when they are piped. Assessments showed that many districts of Emden do not hold the capacity to process a heavy precipitation event. At least when a 160-168 l/s hectare as rainfall intensity and a 5 year return period is used as measurement. Not all districts have been assessed, however, analyses of Transvaal, the inner city, Friesland, Herrentor and Borssum indicated that problems might occur during heavy precipitation events.

Also open drainage structures reveal sensitivities towards flooding making surrounding areas vulnerable to flooding. The DAE and the BEE view the Volkswagen plant and Frisiapark – both major industrial complexes- as critical.

> "*The VW plant is standing on artificial created space which are subject to sagging and subsidence. […] We are moving towards a whole.* […] *There are some drainage routes but those are only long ditches. Some are bigger, but again only ditches. No deeps or channels* ".

The encountered situation regarding subsidence of the terrain, the prevailing drainage concept of long ditches but also large-scale sealing in that areas – e.g. the vehicle transshipment places and production buildings – makes that area vulnerable to flooding.

4.3.2 Social sensitivities

Social sensitivities have been associated with social activities and socio-economic dependencies which can elevate the risk to experience flooding. In this regard, an identified social sensitivity is the behavior towards the obligation to clean private owned water bodies in the urban areas. All interviewees indicated that the neglect of this formal requirement is a major problem in Emden. According to the fire department and the city representatives, reasons for this behavior has often been linked with the occurring generation gap.

> "*I live in an older village with many elderly people. As has always been said, if there is a ditch somewhere, closing it is forbidden. Behavior has changed. In the past people where more aware of how important it is. They kept their ditches in an excellent condition. Regarding the younger generation, one has to say, it is decreasing*"

In the contrary, farmers in the rural areas of Emden show the opposite behavior: "*It is a vested interest of the frames that the spaces are provided with a well-functioning ditch system. We are under NN here. Water needs to be drained fast and if there is a blocked ditch, water accumulates*".

The lack of protection of household regarding the installation of non-return flaps in basements is also of concern.

> "*A lot of people who are living in low-lying areas and potentially possesses a basement do not take preventive measures by installing a non-return flap. In some cases, in Herrentor, people's basements were flooded 2-3 times within a few years. And then they are getting angry and say: Dear city of Emden, you do not have control over your drainage system*" says the fire department.

Even though a statute in the local law of Emden says, that every building with a water inlet beneath street level requires a non-return flap, residents seem to make the city accountable for flooding. Therefore, public understanding is not that strong when it comes to take action by themselves.

4.3.3 Economic sensitivities

Economic sensitivities have been related to economic losses due to flash flooding which can cause a standstill of production with impacts for the whole system. In Emden economic sensitivities are mainly related to the Volkswagen plant and the industrial park Frisia in the south of the city at the harbor area. Business interruptions due to flooding in those areas would mean high economic losses for Emden and the state Lower Saxony which is a stakeholder of the Volkswagen AG. The Volkswagen plant is the largest employer in Emden with 9700 employers (Volkswagen AG 2015). This is more than a quarter of the overall workforce of Emden. The correspondingly associated purchasing power is also securing a great number of jobs.

Also the businesses and shops located in Harsweg between Auricher street and Klaus-Groth-Street can be considered as economic sensitive since it marks a large shopping area of Emden which partly secures the cities provision with food and material goods. Experienced flooding at the Klaus-Grothe-Straße and drainage problems in that area makes it a critical point.

4.3.4 Discussion

The empirical data show that Emden has some areas which indicate higher vulnerabilities to experience a hazardous situation. Areas which show socially constructed drainage problems regarding blocked, filled and piped water bodies can hinder a proper drainage and reduced the retention capacity of the drainage system. Especially certain properties in Transvaal and Conrebbersweg stand out. Incorporating runoff influencing social behaviour as hydraulic bottlenecks in risk analyses may complement the assessment of risk (DWA 2015).

A second issue also refers to drainage bottlenecks. Here, locations where reliable drainage concepts are still missing or where drainage is difficult due to unique environmental conditions has to be pointed out. Processes of sagging and subsidence are viewed as problematic in Emden since they damage existing pipework and further lead to low points which complicates drainage efforts by creating a space for water to accumulate. The district of Harsweg but also areas on the younger marshlands in the southwest of the city -e.g. Volkswagen plant and Wybelsumer Polder- experience such processes. Investigations about soil behaviour and future development can indicate potential future drainage problems and field of actions to encounter such problems.

Further, drainage problems which are connected to missing drainage concepts are often associated with the prevailing length of ditches to the next deep or channel. The identification of such long drainage routes and a closer hydrological examination relating to the complete system can reveal additional problematic ditches.

The data also indicate that low-lying areas are generally prone to flooding. District such as Conrebbersweg, Harsweg, Barenburg, Wolthusen and partly Borssum are low-lying and generally more prone to potential flash floods then others making them areas of risk and thus to prioritise in future assessment.

Another factor indicating risk areas is the performed hydrological assessment of the rainwater sewage which showed potential problems regarding undersized pipework. The harbor area, the inner city, Transvaal, Friesland, Herrentor and Borssum showed that the rainwater sewage system is not capable to process higher water volumes in case of an extreme event. The specifications of the sewage- more specific: that constant water levels exists- have to be taken into account and should be considered in future assessments.

4.4 Adaptive capacities to flash floods from an expert based perspective

Based on the given answers during the interview performances, issues regarding the adaptive capacities of Emden are presented in the following.

4.4.1 Physical planning and engineering

Physical planning and engineering here has been associated with threshold capacity building, meaning all structures, measures and activities which can decrease the probability of exposure. Beneficial for Emden in this regard are the many ditches, deeps and channels which hold a high retention capacity. As city representatives put it: "*we have many small ditches and those can hold a huge amount of water. This is an important factor. Until these are filled up, a lot of water has been collected"*. The particularities of Emden's drainage system are thereby associated with a couple of features which favor a fast water drainage in case of a rain event. The main advantage of Emden is its location close to the pumping station/sluice Knock, but also to those in Borssum and Oldersum. Also short drainage ways from ditches to connected deeps and channels and finally to the pumping stations are associated as advantageous. An additional feature which can increase the retention capacity is the interconnectivity of the drainage system which is often referred to "Emder water circus". This description refers to the different water levels regarding the harbor, the drainage territory of the DAE, low-lying areas, which need additional pumping, the drainage territory of the DAO and the water level of the Ems-Jade-Channel.

> *"There are many overflow structures and a special sluice, the "four-chamber-sluice" which can be open in four directions. It is possible to transport water from the Jade-Ems-Channel via the Fehntjer Tief to the drainage territory of the DAO. Water can be transferred to the territory of the DAE or into the harbor of Emden*" says the DAE.

By turning over the water surplus of one area to another flood mitigation is possible. The pumping station in Borssum is thereby viewed as a central flood risk decreasing measure since it functions as an emergency

pumping station, where water can be transferred to, if necessary. Also the inland harbor is perceived as a major risk reducing structure. "*If we are unable to drain, we always have the harbor which can be filled up. It is a huge retention basin when natural discharge is not possible The water level can be certainly increased by about a meter*" says the fire department. However, turn overs are also limited given the different water levels. Disadvantageously in this regard is that the DAE is not able to transfer water to the territory of the DAO.
Another feature which can increase the resistance to stresses in Emden is the Große Meer in the northeast outside the city borders which is about 350 hectares large.

> The DAE states that "*four weirs were built around the Große Meer. It is now possible to hold back up to 1.050.000 cubic meters of water. When we close the weirs and start pumping the surrounding areas are being drained faster. This is adventurous for Emden since water coming from the Trecktief via the town moat to the Larrelter Tief are being hold back thus reduce the water levels in Emden".*

However, this measurement requires a certain lead time, also dependent on the season, soil moisture and amount of rain in the system. "*If we start pumping in Knock, it takes about 2 hours until Emden is noticing* it".

Since the event of 2013, the city has learned its lesson and improved its drainage system at some critical points. The exposed Lindengraben but also the railway underpass received pumping stations, which discharge the water to the nearest deep. Eschenweg and Likeweg experienced a strengthening of their drainage routes and a mobile high-performance pump was acquired in order to be able to pump water from the Likeweg to the surrounding field. In the Tunerstraße the old rain pipes got replaced by larger ones. Nevertheless, those measures have not been tested by a heavy precipitation event.

Concerning the drainage system in Emden, functioning pumping stations are essential, not only to discharge water over the dike line when a natural discharge is not possible, but also to guarantee certain water levels in areas with differences in altitude. In order to resist stresses regarding dysfunctional pumping stations, the city of Emden as well as the drainage associations hold mobile floodwater pumps which can fictionally replace failed equipment. However, far reaching complication, such as power failure due to flooding of transformer stations or broken electricity cables can cause severe problems. The DAE says "*if the power supply fails, the drained low lying areas would be flooded*". Even more problematic would be a dysfunction of the pumping station/sluice Knock. Even though an emergency generator exists which can operate the lock, pumping is not possible. Furthermore, in time emergency response procedures to replace the pumps with mobile ones or to receive according emergency generators, which are able to run the 600 KW pumps, are technically not possible. Large capacities of the city to resist stresses are dependent on a functioning power supply.

The creation of retention areas for sealed surfaces over 18.000 m² is a formal obligation in Emden and needs to be reported to the drainage authorities. Retention basins can be generally found at and around the Volkswagen plant and Frisiapark due to the large scale-sealing of those locations. In general, the drainage responsibility of the critical point Volkswagen plant regarding the creation and maintenance of

drainage routes and retention areas lies in the firm's own hands. If acquired, the sealed parking spaces of the plant can be used as inundation areas for retention purposes.
Water retention is also integrated in urban-land-use planning procedures. New developments have to create efficient drainage and rain retention concepts, which are also monitored by the water authority. Also non-return flaps are - according to the city law which refers to DIN 1986- compulsory to implement.

4.4.2 Social Capacity

Social capacities have been associated with abilities to act in an informed manner in case of a hazardous event so as to prevent damages. This in turn requires awareness and knowledge about the potential risk. However, the issue flash flood and accompanying threats is not a major concern for the city administration of Emden and awareness-rising measures are not being performed. "*We have something about floods and waters in general on our webpage. But we do not have awareness-rising programmes yet. It is not yet the time for that"* states the city. Individual confrontations with the problem is still low and limited critical reflection on the topic is common. Regarding this the city also states that "*more people needs to be affected, maybe then a request might come*". On this basis, it can be assumed that public awareness is relatively low. An early public discussion and information provision might improve private hazard response and thus limit damages.

Also, public recognition of the importance of the drainage system and being aware that maintenance and cleaning of ditches is crucial to withstand flash flood stresses can increase social capacity. Regarding this, the local water authority is responsible to monitor and inform private owners to keep their water bodies in a good shape. The city states that "*what we often do is to inform the people with flyers about the importance of ditch maintenance and that they would work against themselves if they do not do that"*. The water authority also holds the basis to take legal steps in case private owners do not meet their obligations. However, such mechanisms are generally not taken in Emden. The problem that ditches are filled up, blocked or build up so that cleaning equipment cannot reach those areas, indicates that awareness is lacking and that formal procedures do not fully work. Misbehaviour might be connected with the citizens' age and how long people have been living in the city. Elderly people are viewed to be more aware of the problems than younger ones according to the fire department and the city of Emden.

4.4.3 Economic capacity

The economic capacity of Emden in regard to create potentials to withstand stresses are viewed to be connected to financial resources to improve more drainage capacities. The responsibility, according to the cities view, is by the BEE to take action. The in-house operation waste removal, urban drainage and street cleaning of the BEE has a certain budget for investments. Nevertheless, those funds are not exclusively to improve the rainwater system. Wastewater sewages, treatment plants and other obligations also have to be financed. Further, investments for underground construction purposes are -according to the BEE - in 80 % of the cases coupled with road works and works of suppliers. The circumstances that roads constructions receive public grant funds and that planning is generally faster forces underground constructions to "tag along". Large sums of money are being spent to replace pipework where street works are being done.

> *"I would like to take own measures but I am narrowed since street constructions are receiving funds for many measurements and are able to implement them quickly while I have to invest the full amount of money. This restrains me to implement measures which we determined in the course of our hydraulic calculations. I do not have enough financial resources*".

Financial resources are also of concern for the drainage associations to invest in improvements. There is an investment fund for inland flood prevention where financial support is granted with a 50/50, 70/30 or 90/10 funding, depending on the project. Hereby, the main financial proportion is carried by the service providers responsible for the local flood protection like the DEA. In their view, funding however, "*is limited since all drainage associations and others can get access. The financial frame is limiting us*". Another issue which limits drainage associations to invest are missing spaces to broaden existing water bodies. On the one hand is the monetary factor that spaces are becoming more expensive; while on the other hand more buildings are blocking extensions.

4.4.4 Management and institutional capacity

Flood forecasting in Lower Saxony is built upon a water balanced model which enables calculations of water level and discharge by using high-resolution climate data. Parameters like river runoff, precipitation, temperature, humidity and global radiation are tracked in real-time on which basis forecasts are being performed. For that a national database is in use in which among other the German Meteorological Service (DWD) and state owned networks integrate their measurement data. A second database include different weather models of the DWD on which basis precipitation forecast for runoff calculations are being performed. The major proportion of forecast concentrate on potential river flooding while flash floods and possible areal inundation -both regarding possible modelling efforts and forecasts- are not foreseeable and calculable.

> Regarding this the Flood Forecast Centre Lower Saxony states: „*We cannot predict in detail where and with what intensity a rainfall is coming. That is why we refer to the DWD who provides projections of how much rain might come at least in the next 24 hours. For forecasting a sudden flash flood, the problem occurs that the available numerical weather forecast input data is having a raster surface of 2,7 square kilometres which is partially not detailed enough for local heavy precipitation events. […] The problem is thus that heavy precipitation events cannot even be exactly detected by the DWD or any other weather service. That is why flood forecasting is very difficult with regard to convective rain events and sudden flash floods. The best way so far is to observe the course of the rain front by radar technology and see if a response is necessary*".

Where and when heavy precipitation events occur is always uncertain. If it is possible to predict, warning times consist of a couple of hours. With references to Emden, this means that flash flood warnings are on short notice or not at all available. Timely qualitative provisions of warnings about high risk situations originating form extreme weather events which enable adequate response is a concern for civil protection in Emden. On a city and municipality level, weather warning is undertaken by the DWD, which informs city authorities about potential weather conditions. Warnings about potential rain intensities, however, are often perceived as not exactly enough.

> Accordingly, the fire department says: *"sometime you receive warnings about a heavy precipitation events. Next you check the sky but sees nothing. Then 10 min later you "drown". But you also receive warning saying for example that at 18 a.m. 50 litre of rain is coming. But at the end there is nothing*".

The consequence of imprecise warning is associated with a loss of their credibility. Additionally, the quantity of warnings is also perceived as a risk increasing issue.

> Again the fire department states that "*meanwhile all this warning has reached a critical proportion. If you start calling your disaster staff in the middle of the night because of some warning and nothing comes, then people start to say that you do not have to call them the next time. […] I am not a friend of all the warning, man becomes dull*".

Therefore, flash flood response in Emden is often based on improvisation. That does not mean that the city is unprepared. Depending on the scale and urgency of the situation faced, different disaster response procedure are in place. Small scale threats are being faced in the frame of the local civil protection and disaster response service (BZK) including resources such as the fire department, THW and regional interagency aid. Large scale threats which exceed the capacity of the BZK mark the tipping point for the creation of the disaster staff in which different structures -like the BEE, rescue and aid organisations, police, BZK and sometimes the Federal Armed Forces- are being integrated. For this situation different established protocols like alarm plans, civil protection plans, accessibility lists for local private businesses and evacuation plans exists which are constantly being updated.

> Further, according to the fire department, emergency situations are being exercised and responsibilities arranged: "*At least every quarter, all executives of the different units come together to get to know each other and to allocate responsibilities so that everybody knows what to do and what to expect in case of a disaster. Also training and teaching is being performed there. […]. Annually, we run annually up to 3-4 practical exercises".*

However, the public is excluded from such procedures. In case of an emergency, the city of Emden is using the KATWARN-service, a warning and information system which provide information about risk on individual cell phones. Further, 80 % of all emergency response vehicles possess speakers. Up to 40 vehicles can be used to inform the citizens of Emden about potential threats. Also usable for warning proposes are radio and television.

The BEE is handling the flash flood risks in a more practical way. *„We live with the situation that rainwater could be flooding streets, so that we have up to 4-5 cm on the streets. Usually, after 2-30 min everything is gone".*

> Awareness raising and the creating of a risk culture is viewed as important: "*The aim is to create more awareness. Citizens need to understand that pure technical safety is not possible. We cannot implement rain pipes which can absorb everything. We need to rethink, flooding occurs and we can only try to manage it*".

The proper allocation of responsibilities can also raise adaptive capacities. Regarding emergency response, the city seems to be well-positioned. The issue of drainage waters and the responsibility of control examinations is subject of discussion. The German term "Gewässerschau" is used to describe the temporal examination of all water drainage related facilities by the city and other parties. Regarding Emden, such a Gewässerschau is not existing. The drainage associations do control their water bodies category 2 (water body's with a trans-regional importance) every year, however, for private owned water bodies category 3, a Gewässerschau is not performed. *"I think that is critical that such an inspection is not existence. […]. Right now the BEE is inspecting waters, even though it is not our task, we are responsible for the sewage system. […]. It is the responsibility of the water authority*" says the BEE.

Cooperation among agencies is also important to increase adaptive capacities. In general, all persons questioned responded positively to collaboration and involving each other in flood risk management. BEE and the drainage associations are *inter alia* included in questions regarding city development and land-use planning due to water management reasons. Also cooperations between the drainage associations, BEE and the city is viewed as positive. A point which is viewed negatively is the internal communication between the road construction office and the urban drainage office of the BEE.

> "*Even though possibilities exist, communication is difficult. That is why new remediation areas are being identified where I have to say, this is not possible regarding drainage. I have to start my work at the lowest point and not at the highest. If I implement a larger pipe at the highest, I consequently have to connect it to a smaller one. By doing so I consciously create a point where flooding is more likely*". The same accounts for new development projects in which -according to BEE- underground constructions *"are much too often left out of the planning"*.

4.4.5 Discussion

The results show that Emden's capacity to process flash floods is dependent on the interplay of various drainage performances of different actors and systems alike. Maintaining pumping capacities is an essential requirement to secure drainage of accruing water surpluses which in turn is connected to a stable power supply. Context specific characteristics of Emden, such as the reliance on the pumping station Knock and its unique "bathtub" location with the associated differences in water levels (Emder circus) within city boundaries which enables turnover of water volumes are determining the possibility and extent of potential flash flood events. Also potential couplings of hazardous events such as the simultaneous occurrence of a storm surge, a local heavy precipitation event, increasing inland water volumes coming from the Große Meer, and blackouts due to mechanic failure or as a consequence of flooded or destroyed facilities are determinants. Thus, activities to increase the cities adaptive capacities should consider these threats by incorporating them into future scenario crafting for flood risk assessments. This would be in line with the UNISDR (2005), Wisner (2004); Turner et al. (2003) who stipulate the need to incorporate different risk assumptions in flood risk simulations and scenarios to assess the factors and conditions by which a system and its individual components are put at risk. In this regard, a total failure of pumping stations should be taken into account. Further, it is not enough to assess the run-off behaviour by simulating a precipitation event which irrigates the area in a homogenously way. Flash floods occur locally. It is advisable to run different simulations with rain intensities equally to or higher than those experienced 2013, and to use different courses which the rain event can take. Simulations can further be coupled with potential occurring storm surges, blackouts and incoming inland waters. To set a first focus, districts which showed sensitivities regarding flooding –such as Conrebbersweg, Tranvall, Herrentor and Borssum- can be preferred. Equally important is to assess the water turn over capacity of the drainage system and in what way certain measurements can offer a relieve for the respective districts. In general, scenarios need to be aware of the time dimensions needed until drainage processes are being started or not. Measurements which can increase the retention capacity of the drainage system -such as early pumping activities at the Knock, Borssum, Oldersum, closing weirs at the Große Meeer or turn overs of water within the system- are subject to automatic procedures and human reaction. Adequate warning time might not be given which limits a temporal response to take action. The Knock for example needs about 2 hours until pumping efforts are being noticed in Emden. Including different system response times in scenario crafting is thus advisable.

The potential mismatch between flash flood warnings and emergency response by drainage officials and the BZK is also viewed as a challenge to better cope with potential stresses. Here, as Marchi et al. (2010) pointed out, the problem of the short time dimensions of flash floods and the resultant difficulties to predict flash flood generating storms and resultant flooding is visible. In this regard, the quality of warnings need to be adjusted to the regional context, since heavy precipitation events will clearly cause another catchment response in the predominant low-lying environment when compared to more elevated basins. Even though, the BZK sees itself prepared for sudden hazardous flash flood conditions by using improvisation skills, the BEE and the drainage associations are in many cases bound to certain lead times to activate drainage mechanisms or to create more retention volume in their systems. For FRM proposes, arrangements and coordination between those actors are essential in order to reach a joint flash flood response. This would be in line with the more interdisciplinary and multi-stakeholder orientation of FRM (see e.g. Wolke 2008; Müller 2010) and would facilitate a more proactive approach. Since flash flood warnings are obviously inaccurate and normally not existent, rainfall forecast by the DWD and closer monitoring of course and development of rain fronts are the only indicator for potential occurrences. It is recommendable to implement a working group which defines rain intensity and potential rain behaviour on which basis action is taken place. Generally, the DWD is able to make localized rain forecast about a day ahead, giving a 24-hour lead time which would be enough time for the drainage associations to decrease the respective water levels they are running in their system. Also the redistribution of resources is an issue which can contribute to improve the joint flash flood response. An example addressed by the

BEE was to financially support the DAE for pumping activities at the Knock in order to create more retention volumes for the city.

FRM views flood protection as a society wide task. Decision making for management processes to reduce flood risks should be performed on consensus and by incorporating all kinds of action fields and stakeholder attributed to FRM (Müller 2010; Buckle, Mars & Smale 2000). Cooperation and improved ways of communication are viewed as an essential precondition to overcome prevailing problems. Regarding Emden, it is important to not ignore specific field of actions and actors. Here the field of underground constructions and their specific requirements for the allocation of new development and remediation areas is important. Greater consideration in decision making of this field would safe resources but also ensures a functioning drainage. Further, the allocation of responsibilities regarding the question of who is in charge to control and ensure the functionality of water bodies is also important and normally regulated by the Water Resource Act (WHG), Water Framework Directive (WFD) and the State Water Law (NWG). However, the legal obligation of landowners to secure and maintenance their water bodies and a proper runoff is not being fallowed in some areas which indicates that the legal obligations might not be considered as a formal institutional motivation to make an effort. Also unawareness of younger citizens and landowners regarding their obligations is problematic. Property owners often hold the city and service providers accountable for occurring flood damages and do not see themselves in the legal duty to protect their properties. Therefore, it is advisable to include private actors in FRM processes and to formally address their responsibilities in FRM moving towards a more decentralized FRM approach.

Also in public institutions deficits in the allocation of responsibilities have been encounter. In this regard, the legal formulation of a municipal duty to implementation the Gewässerschau and a clear definition of who is in charge of what and what formal mechanisms can be used to ensure the drainage functionality is recommended. So far there is a mutual agreement that people have to maintain and clean their ditches among all actors. However, what is missing, is a clear top-down regulation by the head of the municipal planning and building control office. An inclusion of the community and private owners of water bodies category 3 can be included in the formal institutional context of the Gewässerschau process which can alleviate awareness and impel people to take actions due to the public display. Integrating responsibilities of landowners to assess and evaluate their own rainwater processing in a formal institutional context can stimulate flash flood adaptation and increase legal responsibility.

Another issue which needs formal recognition are development-, and land-use plans which should graphically and textually communicate where cleaning stripes (space left open for cleaning equipment) have to be kept free. This direct step would strengthen the structural policy and the legal stipulation that landowners are responsible in making sure that their property meets the legal demands.

5 Conclusion & Recommendations

The initial objective of this study is grounded on two main goals. The first one is to move the flash flood problem in low-lying coastal areas more into the academic focus by adding understanding of how local knowledge can help by assessing the preliminary flash flood risks and secondly of how to improve flood risk management based on this knowledge. In this chapter a reflection is being performed of how and to what extent these goals have been reached.

5.1 Empirical and theoretical reflection

In order to understand how flash flood risk is experienced, perceived and managed in the city of Emden, this study made use of an expert-based approach. Local flash flood risk related knowledge available with different actors with fields in FRM have been interviewed to explain and visualize the physical and behavioral factors of risk, namely flash flood hazard, vulnerability and adaptive capacity.

A qualitative method in form of semi-structured interviews together with a spatial mapping tool were used to depict the initial flash flood risk situation and context and further bring out and understand the point of view of the local experts regarding flash flood risk issues. The information and perception found were analyzed by implementing the defined notions of flash flood risk in a preliminary risk assessment.

5.1.1 The characteristics of local knowledge in preliminary flash flood risk assessments

The theory that local expert knowledge and knowledgeable people can be used to preliminary asses the flash flood risk depends upon a series of issues. At first, expert selection is crucial. In general, flash-flood risk related knowledge is available among experts and knowledgeable people. They have developed a broad and diverse amount of knowledge over the years, especially those who are confronted with flood-related risks on a daily working basis. However, the quality of information usable to assess risks is dependent on the practical link, meaning that experts which have to deal with local flash flood related problems throughout their ward possess a more comprehensive understanding of flood problems. Experts in the field of service provision, such as water management and disaster response, showed an extensive knowledge in terms of identifying and characterizing flash flood occurrences and consequences. The obtained information was also more coherent and precise, in particular in regard to the identification of inundation areas and physical sensitivities. This does not mean that other actors questioned were insignificant for the assessment. If anything, local knowledge is context specific. Information from authorities at municipal level for example reflected the rather social context and dimensions regarding the flash flood problem and further provided information about administrative issues. Thus, for the assessment of flash flood risk based on expert knowledge, the incorporation of a variety of different knowledge systems is found to be crucial which is also in line with the collaborative notion in FRM.

5.1.2 The application of local expert knowledge in preliminary flash flood risk assessments

The process of understanding the multifaceted nature of risk, vulnerability and adaptive capacity in the context of flash flood hazards takes up a large part of this research. The prevailing variety of concepts and factors of how to define and assess risk, both qualitative and quantitative, has proven to be a challenging issue for the drafting of a conceptual model and used for data collection. The predominant technical orientation to assess flood risk in the practical realm are in contrast with qualitative approaches. However, the conceptual model has shown to be a valuable tool to collect risk related empirical data of knowledgeable people and expert in a local context. Nevertheless, the model also showed some deficits.

Knowledge on flash flood hazards

The identification of flash hazard related knowledge based on experienced flood occurrences and intensities in this study is ambivalent. Flood occurrences regarding experienced inundations showed good results (see Map 6). The assessment indicated that Emden experienced spatial distributed flooding of urban areas, reflecting the local appearance of flash floods. The severity of such flood occurrences were found to be relevant, but not serious. However, the allocation of inundation areas to certain events in time and space could not be performed. Only for an event in 2013 a clear distinction of flood occurrences was possible. It may be reasoned that memory of specific events decay after a certain period of time thus leading to these knowledge gaps. This would also be in line with similar observations made in other studies (see e.g. Peters Guarín 2008). Another issue, which reduced the quality of the empirical data, is the resolution and accuracy of inundation areas. Since their identification relies on qualitative statements and markings on base maps, results reflect rather rough estimations. Also the identification of flash flood intensities proved to be difficult. Statements such as "the boat is full" or "the shoes got wet" are not useful to determine inundation depth or rainfall rate and distribution. In this regard the benefits of "technical" knowledge like measurement data are undisputed. However, since such technical information are in many cases not being documented due to measurement difficulties, the obtained qualitative and spatial information about the flash flood hazard factor show benefits for risk identification purposes and hence help to complement risk assessments. It is recommended to take both, technical and qualitative data sets into account if available.

Local flash flood vulnerabilities

So far, despite the fact that Emden was spared from major effects of flash flooding, it should not distort its vulnerability. In this regard, the conceptual model showed its strengths particularly in the identification of physical and social sensitivities contributing to vulnerability. Knowledge about local conditions causing or supporting flood occurrences are well known among experts. The assessment of such components revealed that aspects such as the undersized rainwater sewage systems, processes of sagging and subsidence influencing water discharge of sewers blocked or filled up drainage ditches as well as predominant low height relations can increase the risk of flooding in many areas of the city. However, also in this regard the rough accuracy and resolution of spatially identified vulnerabilities to flooding (e.g. drainage problems) has to be mentioned. It is recommended to improve physical sensitivities identification by local on-site inspections for specification purposes. The assessment of the social sensitivities contributing to vulnerability proved to be beneficial in respect to identifying people's behavior and how their action can increase the risk of flooding. In the case of Emden, the negligence of private water owners to meet obligations important to ensure a proper water drainage or an unambiguous assignment of responsibilities regarding functional testing of water bodies were found to raise flood risks. In this regard, the unawareness of younger people was indicated to contribute to the problem. Concluding on these findings it is recommended to increase awareness about the importance of private owned water bodies for the cities capability to process heavy precipitation events and to establish a Gewässerschau in a cooperative way which includes public and private institutions (e.g. the BEE, drainage associations, the city, VW and the public). Also, more awareness rising programs on the city level, which inform the public about the threat posed by flash floods and what preventive measurements exist, is advisable.

Also the assessment of system exposure regarding structures and facilities brought up a number of results. However, they suffer from the same deficits in accuracy and resolution concerning the areal identification. Yet again, an on-site examination with respective experts could have helped to specify location and structure type. It is also helpful to make classifications regarding the importance of exposed structures in addressing the needs of the populations. Structures with important functions can be prioritize in flood risk reduction and mitigation activities.

The assessment of economic sensitivities in this study were primarily focused on the Volkswagen plant. Since the company is responsible for its own water management and an interview with a Volkswagen representative could not be performed, conclusions are hard to perform. Yet, using business and economic importance as indicators, flooding of the Volkswagen plant showed to be a risk factor for the city. For Volkswagen it is recommended to perform investigations about subsoil processes to identify areas for improvements regarding their drainage concept. This might prevent loss of productions and economic damages.

Local abilities and capacities to process flash floods

Generally, the conceptual assessment of adaptive capacities by the components used (see chapter 4.4) showed good results. Especially in combination with the identified vulnerabilities, the assessment reveal activities and measures to increase and strengthen capacities to process heavy precipitation events and hence improve FRM.

In general, the assessment of the resistance to stresses showed that the city holds large capacities to mitigate or prevent an event. Here, the retention capacity of the drainage systems and the possibility to turn over water were found to be crucial. However, the inherent short time dimensions of flash floods make it difficult to exploit these capacities. Regarding Emden this is especially true for pre-pumping activities to reduce the water levels in the city thus increasing retention capacities. Therefore, it is recommended to establish a consensus based triggering point, where retention increasing capacities are being started. A suggestion is to focus on rainfall forecasting by the DWD. Forecasts which exceed a certain threshold can be used as starting point for measurements.

The drainage system and its retention capacity is also associated with vulnerabilities discovered since it rests on a functional power supply. Scenario crafting and management efforts should include power failure considerations and thus technical failures of pumping stations which can lead to extensive flooding. Also couplings of risk sources, such as increased sea water levels, heavy precipitation events and higher inland runoff volumes should be considered and connected to drainage failures. Securing a functional drainage and pumping should be viewed as priority and supported by redundant designs such as emergency power generators, mobile pumps and different electricity providers.

Economic capacities like existing resources for flash flood adaptation and mitigation were found to be limited or not fully exploited. Circumstances such as lack of funding, weak official compliance, high base prices, internal communication problems, and high maintenance as well as renovation expenses of old structures hinder different actors to take action. In this regard it can be said that Emden is lacking a comprehensive strategy of how to financially and organizationally address the required adjustments to reduce flash flood risks. Resources for improvements are currently not specified rather than distributed to various cost elements limiting major renovations and projects. Pipework, for example, are normally integrated in planning and project management, however, in regard to other disciplines, it experiences too little attention concerning funding and prioritization. It is thus advisable to create a platform to stimulate collective action and interaction in flash flood adaptation. Such a platform can facilitate collaboration and coordination amongst the actors involved in FRM and may ensure a consensus based action pan to tackle flash flood risk.

So far, problem recognition regarding the flash flood issue is in a mature stage in Emden. Drainage associations, the BEE and the city administration are aware of climate stimuli and possible negative effects on the water regime which is why the region participates in a couple of projects such as KLEVER (climate optimized drainage system for the territory of Emden) and COMTESS (Sustainable coastal land management). The drainage association Emden is building more capacities by developing a new drainage master plan for the region based on project findings and also the BEE hopes for more integrative urban drainage concepts to increase retention capacities. Nevertheless, in order to make Emden more adjusted and "rainproof", it has to shift from the perception that the municipality and service providers are the key actor in flood risk management and flash flood adaptation towards the recognitions of the public as key stakeholders. The assessment of the management of risks and institutional capacity proved its quality by revealing these tendencies. Risk governance processes and networks require a distribution of responsibilities and tasks as perquisite (Ward et al. 2013). Informal institutions such as housing associations and residents have to be made aware of their important role they play in FRM process. So far, awareness building and information exchange regarding flash flood threats by the municipality is limited and connected to public requests in case a flash flood event may lead to an increased interest. However, creating public problem recognition at an early stage and a sense of urgency to take action facilitate awareness and motivation to perform flood risk decreasing measures. Efforts to strengthen the abilities of the public to process flash floods is also viewed as beneficial for emergency response. The sudden nature of flash flood events and the resultant decrease of warning accuracy and quality requires improvisations skills of actors in emergency response. In this regard help for residents may be delayed due to short warning times. Rising awareness and individual preparedness of citizens is thus crucial to cope with flooding.

Concluding from the empirical and theoretical reflection, a revised conceptual model is elaborated in Table 3.

Table 3: Revised conceptual model, Source: (Author)

Risk factors and components of the conceptual model for flash flood risk analysis		**Indicator and parameter used to qualitatively and spatially represent the preliminary flash flood risk based on expert judgment**	
Hazard flash flood	Flood probability and severity	Occurrence and intensity	-Identification of experienced and perceived flash flood occurrences -Identification of determining conditions of past flood occurrences (physical conditions, such as drainage failure and anthropogenic and natural influences) -Experienced and perceived inundation depth, areal extent and consequences of perceived flash flood events
Vulnerability	Physical exposure and physical sensitivity	Location, buildings, transportation systems, utilities areas at risk, buildings, drainage systems and sealing	-Properties within experienced and perceived flood zones: general building stock, essential facilities, high potential loss facilities, highways, railways, ports, water and wastewater, electricity, gas and oil facilities -Existence of basements and underground car parks in flood zones -Surface elevation of the terrain/low-lying areas -Judgement upon the maintenance and quality of ditches and drainage/rainwater/sewer systems and influencing factors -Perceived and experienced anthropogenic and environmental processes
	Social sensitivity	Age structure, newcomers, behaviour	-Age of the residents -new to the city and unfamiliar with the local environment -Citizens unawareness and actions (e.g. interventions into water drainage and runoff)
	Economic sensitivity	Businesses	-Business size and judged economic importance for city generally and/or for the livelihood of citizens

	Physical planning and engineering	Resistance to stresses, applied building codes	-Technical safety, resistance of structural/technical mitigation measures such as drainage systems, pumping stations, retention areas etc. -Consideration of risk decreasing requirements
	Social capacity	Risk perception, public emergency response drills	-Existence of public risk awareness -Existence, tests and exercise of plans including public participation -Responsible rain water treatment on properties (maintenance of ditches, retention of rainwater)
Adaptive capacities	Economic capacity	Recovery tools and resources	-Insurance marked to transfer flash flood related damages -Resources and willingness for investments/adaptations and potential barriers to perform such activities
	Management and institutional capacity	Monitoring, risk governance	-Monitoring networks: weather radar, precipitation forecasting system -Flood forecasting strategy -Established flood risk management platform, emergency committee -Allocation of tasks and responsibilities among agencies -Established protocols for information sharing -Existence of risk maps and emergency plans -Institutional capacity building/warning skills

5.2 Methodological reflection and suggestions for further research

Reflecting on the methodological design utilized in this study, some advantages and disadvantages appear. The scope on the city level requires a wide range of actor specific data, contextual information and a broad spectrum of topics. The time frame and limited resources for this study however, led to a focus on a relative method used to position the level of observation and of detail. The presented spatial and qualitative information remain somewhat superficial, which is also indicated in the prior chapter. The broad focus on experts and knowledgeable people only represents a proportion of information usable for risk identification purposes and assessment. Some components of the risk framework were not fully grasped. For example, qualitative and spatial knowledge of experts for hazard identification and assessment rather complement technical knowledge and cannot replace it. Consequently, some of the evidence- particularly the spatial data- are not very strong since they lack in accuracy and resolution. Further, the obtained information of risks is based on a limited amount of one sided actor specific views. Due to these circumstances, the broad theoretical orientation of this research can be questioned. Views and knowledge of flood risk are -according to Peters Guarín (2008)- complex. Incorporating more different views and knowledge systems could have improved the results and help to grasp more information about the risk factor components. This may be done by incorporating more interviews with other experts, or including the household level by applying questionnaires and interviews. This could have broadened the view and support the understanding of hazard, vulnerability and coping strategies.

The advantage of the methodological deign applied is that is gives a good and somewhat clear understanding of the cities specific flash flood risk situation, on which basis further analysis and evaluations can take place. In this regard the question of to what extent can local flash flood-related knowledge add value for flash flood risk assessments and management -which is addressed in the previous chapters- is answered. Despite this, it has to be stressed that further inclusions of additional risk indicators and parameters would have complemented the findings. For example, environmental sensitivities, detailed profiles of the build environment and more social and economic indicators such as income and social status could have been integrated.

In addition, reflecting on the research process, some aspects stand out which influenced the response towards the research and the end results. Shortly before the data collection procedure, heavy flash flood events occurred in the south of Germany, like the one experienced in Sinnbach am Inn, Lower Bavaria 01.06.2016. Consequently, politics and media pushed the topic into the public focal and created a new discussion regarding flash flood hazards. Interest and willingness to participate was not at least because of these events relatively high. Further, newly reassembled research projects of how to adapt to climate stimuli –here the project KLEVER has to be mentioned- but also recent heavy precipitation events caused a prior confrontation with flash flood related problems which supported information gathering

As already mentioned, data sources and research methods used in this study only captured a small proportion of empirical evidence about the perceived risk situations and thus affect the results. Focus group discussion, field workshops, household survey and transect methods – see also Peters Guarín

(2008)- can complement the risk picture by incorporating more knowledge systems. This, among other, also creates potential for future research in order to add and improve spatial and qualitative local knowledge about flash flood risks. Some suggestions are:

- A comprehensive research of how individual community member perceive local flash flood risks.
- Exploring the adaptive capacities of community members
- Exploring the possibility to incorporate social behavior in flood risk assessments
- Elaboration of a program to rise flash flood risk awareness
- Translating identified local risk-related knowledge into concrete flood risk management strategies.
- How to develop a flash flood risk platform for the city Emden

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7 Appendix

1. Locations prone and vulnerable to flooding

Table 4: Locations prone to flooding

Locations prone to flooding	
Interviewees 5	Lindengraben "*Everything was flooded there.*"
	Railway underpass (near Johan-Friedrich Dirks (Spedition Gmbh), Petkumer Str.) *"There is always water."*
	Klaus-Groth-Straße *"The whole street was flooded (2016), up to 25cm over the kerbs."*
	Transvaal – Münsterstraße, Dollartstraße, across the Cirksenstraße *"Classical residential areas, family homes, row houses, with and without basements which were flooded."*
	Harsweg *„Here the street was flooded.* "
	Autobahn – exit Emden Mitte
	Transformer station, Borssum -At Wykhoffweg, Birkenweg *"All the buildings were flooded and they almost needed to cut the power"*
	Herrentor *"Here are classical residential areas, family homes, row houses, with and without basements which were flooded"*
	Likeweg and Kiefernstraße *"Houses were flooded"*
	Kaierweg, Ökowerk *"Here we had some problems"*
	Alt Barenburg – Schedermannstraße, Geibelstraße *"Here we often have rain related operations."*
Interviewees 3	Railway underpass- Petkumer Str.
	Conrebbersweg "*In the old part of the district we experienced some flooding since the ditches are in private hands and filled up. It is also low-lying and the water is flooding the houses.*"
	Herrentor
	Wybelsum "*Here we had some problems, as people started to complain.*"
Interviewees 4	Am Lindengraben *"The street is enclosed by two more elevated streets – almost 2 meter higher- and water ran down the street into the houses."*

	Borssum, Eschenweg and Petkumer str. "*This is the main street to Petkum which is about 1-1.5m lower and cause of water accumulations causing flooding of houses in that area.*"
	Likeweg "*We have here a ditch which takes in much water from the rain pipes in Borssum and drains it into the Ems-Seitenkanal. But this area is also low-lying, a small sink. And we needed to implement a pipe into the ditch due to new developments. However, the pipi couldn't manage the incoming water which led to backwater and flooding of the street":*
	Railway underpass- Petkumer Str. *"This is the lowest point where everything flows together."*
	Hamhuser Straße & Memmonstraße – flooded underground parking spaces "*Those underground parking spaces were flooded due to the lowered kerbs to the streets.*"
Interviewee 6	Direction Westerhusen -Westerweg "*Here that area is low-lying and we had some drainage problems leading to higher water levels and wet feet.*"
	Larrelt *"we had a flood situation here- main street, treatment plant – due to a blocked waterway. However, the blocked waterway got cleaned up."*
	Klosterlangenstraße "*We had some problems here. The agricultural areas were flooded.*"
	Moenkeweg (outside map) "People are living in a flat area which needs constant pumping. The water could not be drained faster there."
	Railway underpass- Petkumer Str.
	Conrebbersweg "*Long and small properties, ditches are filled up and are not taken care of*"
	Transvaal "*Ditches are not taken care of leading to problems*"
	Am Soltendobben *"Low-lying areas which have problems when it gets really wet."*
	Moenkeweg- At the Knock "*People there live in an extreme low-lying area. Occurring water could not be drained fast enough.*"
	Wybelsum- Klosterlangenstraße "*We has some problems in that area. agricultural areas were flooded.*"
	Uphusen – Aalstraße, Zanderstraße, Hechtstraße "*There are often higher water levels because the water drainage is done through small and long ditches and the areas is also low-lying. Agricultural areas are often flooded.*"

Table 5: Locations vulnerable to flooding

Low-Lying areas	
Interviewee 6	Area Uphusen and Wolthusen *"There are often higher water levels because the water drainage is done through small and long ditches and the areas is also low-lying."*
	Area Conrebbersweg west *"A housing development is planed here. Very low-lying area."* Area Conrebbersweg North – Westerweg *"Very low-lying where we also had some drainage problems."*
	Area Twixlum east & Areas Twixlum west *"A low-lying area."*
	Area Wybelsum west – Moenkenweg "*People there live in an extreme low-lying area."*
	Area south of the Hieve up to Ems-Jade-Channel – Am Soltendobben *"That are all very low-lying areas which have problems sometimes. Because it is really wet sometimes. The street is called Am Soltendobben. Those areas have problems."*
Drainage Problems	
Interviewee 6	Harsweg- Airport, industrial park *"In the industrial park a functioning drainage concept is missing. At the houses in the area of Harsweg, drainage has to take long way". That is a problematic area."*
	Volkswagen plant & Area Frisiapark *"In that area we do not have any larger discharge waters. There are only ditches, longer ones, some are bigger, but no larger channels or deeps."*
	Wybelsum *"The village has some difficulties. There are ditches which do not belong to the drainage associations and are often being filled up."*
	Through section Am Tonnenhof leadin to the Tyssen-Nordeewerft/Emden harbour *"We had some problems here -also often in the news- but something is being done there."*
	Transvaal *"In the district Transvaal problems often occur. Private owners often do not clean and maintain their ditches."*
Interviewees 4	Emsiger Weg *"We have an unfavorable constellation here. People living there have a counterslope to the street. They have no direct rainwater sewer. Further, there are old ditches which are used for the surface drainage of properties which have to be cleaned by the owners. However, such ditches are sometimes not being cleaned- maybe because of older people dying- and the younger ones don't take that seriously."*
	Klaus-Groh-Straße *"Here we have a critical point regarding the surface drainage by a rainwater sewer. The terrain is about +/ - 0 or + 0,1m. and we have a difficult soil situation. The street is sagging and our sewer system is not since it is founded. So we have a "hill and valley" situation where water levels are rising and time is needed until it is drained. That is not so nice since we have some operating facilities, shops and industrial sites there. Due to the given water level of – 1,27*

	in that area, a lot of pressure needs to be built up in the sewer system to drain the water out."
	Undersized rainwater drainage sewer "*We have hydraulically calculated the rainwater sewer system of those areas which have been affected by the event of 2013. Which are those areas are within the Wallring. So the inner city, up to the harbour, Tranvaal, Friesland, Herrentor and Borssum. We used a 160-168 l/s hectare as rainfall intensity and a 5 year return period. And the result showed that we have to do a lot in Transvaal, some in the inner city area, some more in Herrentor and in Borssum punctual."*
Basement	
Interviewees 4	Inner city, Friesland and Herrentor "*Houses with basements are commonly to find in older parts of the town. The inner city definitely. Borssum, Fiesland and Harrentor. Everything surrounding the inner city upwards do not have basements."*

2. Used codes for data analysis

Codes Flash Flood Risk Emden_ Lennard Nolte	
Adaptive capacity Factor	Physical sensitivity
Allocation of responsibilities	Projects
Barriers	Public awareness
Building codes	Public participation
Communication problems	Pumping station
Cooperation	Rain data
Damages	Recovery
Description sewer system	Relative flash flood risk
Drainage problems	Resistance to stresses
Economic capacity	Resources for measures
Economic sensitivity	Risk areas
Exposure Component	Risk governance
Failures	Scenarios
Fire-brigade operations	Sealing
flood forecasting	Sensitivity Component
Flood forecasting method	Social Behavior
Flood probability and severity	Social capacity
General risk perception	Social sensitivity
Hazard Factor	Solution
Information exchange	Vulnerability Factor
Inundation	Warning
Location description	Warning periods
Management and institutional capacity	Water drainage territory description
Monitoring	Water level
Perception of the flash flood problem	Water management
Personal description	Water retention capacity
Physical Exposure	Willingness to adapt and to invest
Physical planning and engineering	