Decision making on flood maps: Evaluation of risk perception in 2D and 2.5D flood visualizations

GEO 511 Master's Thesis

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Abstract

The increasing frequency of flood events around the world highlights the importance of appropriate risk communication. Based on supranational directives, many countries committed to map flood risks on their territory to increase the risk awareness of the population with regard to floods. For this purpose, two-dimensional flood maps are mostly used nowadays. However, technological progress in recent years encouraged the widespread development of alternative visualization types that allow to use three dimensions. The suitability of 3D visualizations as a risk communication tool compared to 2D visualizations is controversially discussed in the literature. Previous research focused mainly on user preferences and decision accuracy between 2D and 3D visualizations. The influence of different dimensions in a flood visualization on human risk perception has hardly been addressed by studies at my state of knowledge. This thesis aims to fill this research gap by investigating how different visualization types, namely 2D and 2.5D flood visualizations, influence human risk perception. More specifically, this thesis analyzes (1) potential differences in the human risk perception between 2D and 2.5D flood visualizations, (2) what the possible drivers of potential differences in response time between 2D and 2.5D flood risk visualizations are and (3) how individual risk attitudes influence the risk perception. To answer these research questions, a study with 30 participants was conducted. Using a between-subject design, one group of participants was shown 2D flood visualizations, while the other group was shown 2.5D flood visualizations. The flood visualizations showed a flood event for the city of Virginia Beach, USA with a return period of 100 years. The participants of both groups had to rate for each of the 16 different flood visualizations on a risk scale how risky it is to build their personal house on the marked location. The results indicate that participants who were shown 2D flood visualizations rated their risk perception of building a house slightly higher for the same location than those participants who viewed at 2.5D visualizations. In addition, the 2D group needed slightly less time to rate their risk perception compared to the 2.5D group. Furthermore, it was found that the individual risk attitude of the participants had no influence on the risk ratings in the context of this study. The results of this study help to promote the understanding of the influence of different dimensions in flood visualizations on human risk perception. This is of importance because a solid understanding of human risk perception encourages more effective risk communication.

Keywords:

Risk perception, 2D vs. 2.5D visualizations, flood risk

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Contents

List of figures

List of tables

1 Introduction

1.1 Motivation

Maps are not only tools for navigation that guide us through unknown terrains, but also facilitate knowledge construction through visual exploration and analysis of spatial data (MacEachren & Kraak, 2001). It is estimated that 80 percent of all digital data contain spatial referencing such as geographic coordinates, addresses or postal codes (MacEachren & Kraak, 2001). With the continuing growth of data visualization, the general public will become even more familiar with the use of geographic information (Roth, 2009). For example, three-dimensional geo-browsers such as Google Maps are becoming increasingly popular on smartphone devices. The consultation of such services is progressively becoming a normal and everyday activity in most people's daily lives (Wilkening & Fabrikant, 2013). For instance, we can display spatial planning levels on web-based platforms to see whether it is possible or prohibited to camp with a tent at a certain location. This example shows that visual communication through maps is not limited to navigation use-cases. Visual communication is defined as a process of sending and receiving information supported by a visual component (Trumbo, 1999).

Visual communication can be used to send information about a risk situation to the population. This communication of risk aims to improve knowledge about the risk, raise risk awareness and motivate the population to prepare for an emergency with preventive actions (Hagemeier-Klose & Wagner, 2009). Risk communication, can be used to anticipate and reduce damage caused by natural disasters (Charrière, Junier, Mostert, & Bogaard, 2012).

Evans, Todd, Baines, Hunt, & Morrison (2014) pointed out that intensive rainfall and storm events are likely to occur more frequently due to climate change. As a consequence, authorities, spatial planners and the general public have to identify and assess potential threats posed by natural hazards to a greater extent (Evans et al., 2014; Seipel & Lim, 2017). In particular, the increasing frequency of flood events around the world shows the importance of precise and extensive information to protect and prevent people from damage (Hagemeier-Klose & Wagner, 2009). Many researchers acknowledge that flood events are considered as one of the most significant natural disasters and that their frequency could increase in the future as a result of climate change (De Moel, Van Alphen, & Aerts, 2009; Evans et al., 2014; Hagemeier-Klose & Wagner, 2009; Kellens, Zaalberg, Neutens, Vanneuville, & De Maeyer, 2011; Lieske, Wade, & Roness, 2014; Seipel & Lim, 2017; van Ackere et al., 2016).

To support the management of flood risk, the EU has adopted a Directive (EU 2007/60/EC) in which the main task for the member states is to map flood risk on their territory (De Moel et al., 2009). Therefore, flood risk maps are becoming a widely used tool for risk communication, aimed at increasing people's risk awareness and taking preventive actions. Thus, risk communication has an influence on people's general perception of flood risk (Macchione, Costabile, Costanzo, & De Santis, 2019). In recent years, the topic about flood risk perception has become particularly important for policy makers dealing with risk management. Kellens et al. (2011) emphasized that “understanding people’s risk perception and its determining factor is crucial for improving risk communications and effective mitigation policies”. Subjective risk perception is recognized as an important aspect of flood risk management, since risk perception often determines people’s willingness to take precautionary actions. But to what extent does a flood risk visualization influence people’s risk perception? And why is risk sometimes perceived differently by the population?

Visualizations, ranging from static two-dimensional (2D) paper maps to digital maps and three-dimensional (3D) interactive visualizations, play an important role in people’s risk perception (Lieske et al., 2014). New types of visualization in risk communication are available, since flood risk maps are no longer limited to a 2D format. Technological progress in recent years encouraged the development and implementation of new visualization types such as 3D visualizations, augmented reality (AR) and virtual reality (VR). MacEachren & Kraak (2001) noted, “as a result of these changes, maps provide a more valuable window on the world than ever before”. Evans et al. (2014) designed a 3D visualization of floods to raise awareness of flood risk in Exeter, UK. They were motivated by the fact that effective communication of flood risk is a challenging task, especially for communities with infrequent flood experiences. The 3D visualization served as a “wake-up call” for the local community and many people indicated that the visualization raised their awareness of flood risk (Evans et al., 2014).

Nowadays, web-based 2D maps are the most frequently used visual communication practice and the general public can access the maps via internet connection (Charrière et al., 2012). For instance and regarding flood risk, the Canton of Lucerne, Switzerland published an interactive 2D flood map showing the spatial extent and flood-depths of a possible future flooding event (Kanton Luzern, 2016). However, many people have difficulties in interpreting their environment in a cartographic representation (Haynes, Barclay, & Pidgeon, 2007). According to several studies, this is the reason why people tend to prefer 3D visualizations (Biljecki, Stoter, Ledoux, Zlatanova, & Çöltekin, 2015; Kemec, Zlatanova, & Duzgun, 2010; Leskens et al., 2017). These studies revealed that different types of flood risk visualizations such as 3D maps and virtual reality worlds are gradually being discussed in the scientific literature (Macchione et al., 2019).

Past research in this area focuses mainly on the user’s preferences and overall effectiveness of flood risk communication between different visualization types. Previous studies primarily compared 2D to 3D visualizations in order to evaluate the performance of decision-making with respect to the quality of the decisions made (Franz, Scholz, & Hinz, 2015). However, existing research that aims to measure the overall usefulness has not yet decided whether 2D or 3D visualizations are superior (Niedomysl, Elldér, Larsson, Thelin, & Jansund, 2013). Further, there is not much research that focuses on the risk perception of 2D and 3D visualizations and less on decision quality. Because the principles of human perception and cognition can explain why a particular visualization works more effectively than others, my research will compare 2D and 3D visualizations with a special focus on human perception rather than on the quality or accuracy of the decisions (Slocum, McMaster, Kessler, & Howard, 2014).

The results of the study will also help to inform best practices for development of risk maps in spatial planning applications. Especially in spatial planning, there is a trend to visualize data in 3D rather than 2D. This trend does not only focus on bigger cities but also on small municipalities like Buttisholz, Switzerland where the local planning is supported by 3D visualizations (Meyer, 2020). As flood events are one of the most significant natural disasters, I want to investigate how different visualization types influence our perception on flood risk. More specifically, I will focus on the comparison of 2D and 2.5D flood risk visualization. In this master thesis, a 2.5D visualization is used to represent the additional dimension compared to a 2D visualization. The difference between the terms 2.5D and 3D is explained in chapter 2.1. It is important to note that the term 2.5D refers mainly to my own created visualizations, while the term 3D is often used in the existing literature.

1.2 Aim

As mentioned above, many studies have concluded that human flood risk perception has a significant influence on an effective flood risk prevention. But within these studies, the role of visualizations in the perception of flood risk is mostly not considered. However, in those papers in which the visualizations play an important role, the focus is mainly on the user's preferences and decision quality. To my knowledge, there are not many studies dealing with flood risk perception itself and how this risk perception is potentially influenced by different visualization types.

The overall aim of this thesis is to address this research gap by investigating how different visualization types (2D vs. 2.5D) affect our flood risk perception. The focus is not on decision accuracy, but rather on the quantification of the self-perceived risk between two different visualization types.

More specifically, this thesis investigates three questions:

- Investigate how people rate their risk perception when viewing a 2D flood visualization compared to a 2.5D flood visualization.

Those two types of visualizations are compared because they are widely used in practice. Due to the obligation for EU member states to map potential flooding threats in the EU, the visualizations focus on flood risk.

- Investigate the drivers for possible differences in decision response time between a 2D and a 2.5D flood visualization.

Since the two visualizations show the same mapped representation, but differ in terms of dimensionality, measuring the response time is a method to manifest possible differences in information processing between the two visualization types.

- Investigate how people's individual attitudes towards risk affect risk perception.

It is important to consider people's individual risk attitude because it represents, together with the visualization type (2D vs. 2.5D), an independent variable which can influence the dependent variable risk perception.

1.3 Structure

This thesis is structured as follows: In the next chapter, a literature review on flood risk visualization and human risk perception is provided. In the same chapter and based on the current state of research, gaps in research are identified, research questions are formulated and the corresponding hypothesis are presented. Chapter 3 presents the methods used to answer the research questions. Chapter 4 shows the obtained results that are discussed in the following chapter 5. To conclude, chapter 6 summarizes the findings of this thesis and places them in a broader context in order to give an outlook on future research.

2 Literature Review

The following chapter presents the current state of research in the areas relevant to the work. The analyzed literature mainly comes from the fields of geography and psychology. Firstly, an overview of already existing types of 2D flood maps is given. Secondly, the third dimension in flood visualization is introduced and some practical examples are shown. Moreover, the current state of research on the use of 2D and 3D visualizations in cartography in general and on flood risk visualization is briefly discussed. In addition to this, the influence of individual risk perception on the effectiveness of visual risk communication is considered in chapter 2.5. Finally, the literature review attempts to identify research gaps, formulate research questions and present the hypothesis based on the given academic background.

2.1 Terminology

This chapter provides an overview of important terms mentioned in this work, as there are numerous different uses of terms in flood risk management, which can lead to confusion (De Moel et al., 2009).

Table 1: Important terms

Term	Definition
2D visualization	In this thesis, the term is used for 2D maps that "depict the surface of Earth from a theoretical vantage point of directly overhead, in an orthogonal projection" (Schobesberger & Patterson, 2008).
2.5D visualization	2.5D representations are characterized as "single-valued" because only a single z-value is allowed for each point on the XY plane. For instance, it is not possible to visualize balconies or other overhangs on buildings. (Costamagna, 2014).
Flood	This work uses the definition of van Alphen, Martini, Loat, Slomp, & Passchier (2009), which defines flood as "a temporary covering by water of land normally not covered by water".
Flood damage	Damage is constituted in consequences from a flood to human health, the environment, cultural heritage and economy (van Alphen et al., 2009).
Flood hazard	The probability of a flood event (Tsakiris, Nalbantis, & Pistrika, 2009).
Flood risk	Flood risk is defined as the combination of the probability of a flood event and the extent of damage (van Alphen et al., 2009).
Flood risk management	Flood risk management describes the steps and process of managing possible events and/ or reducing their negative effects. This also includes the prevention of existing flood hazards that could become catastrophic events (Wang, 2015).
Flood visualization	In this thesis, this term is used to describe a cartographic representation that visualizes the spatial extent of a (potential) flood.
Hazard	The change of a situation that potentially leads to harm or property loss is defined as a hazard (Wang, 2015).
Oblique perspective	In an oblique perspective, the map user's viewpoint is chosen in such a way that the visualization is been looked at from a side perspective instead of a traditional orthogonal perspective.

Risk	Risk is a function of probability of occurrence and the extent of damage. (Spachinger, Dorner, Metzka, Serrhini, & Fuchs, 2008).
Visualization characteristics	In this thesis, this term is used to describe the nature or the overall characteristics of a visualization type (e.g. of 2D and 2.5D visualizations).

In addition to Table 1, I want to emphasize that flood maps can be distinguished between flood hazard maps and flood risk maps (De Moel et al., 2009). A flood hazard map presents the extent and depth of flooding for a flood event with a particular probability. In the meantime, a flood risk map visualizes not only the hazard information but also the consequences of a flood (van Alphen et al., 2009). De Moel et al. (2009) also distinguish the two concepts in that flood hazard maps contain information on the probability and/or extent of a flood event whereas flood risk maps contain additional information on the consequences.

2.2 Flood visualizations in 2D

Besides the current research about the visualization characteristics of a 2D flood map, an overview of the historical foundation for the development of 2D flood visualizations and already existing types of 2D flood maps is provided. Furthermore, the state of research regarding guidelines for flood map designs is presented.

2.2.1 Historical context

Dealing with flood hazards using maps is not new (De Moel et al., 2009). For instance, the National Flood Insurance Program (NFIP) was initiated in the USA in 1968 (Burby, 2001). In Europe, most flood mapping activities started in the 1990s (De Moel et al., 2009).

The NFIP is a cooperation between the private insurance industry and the local, state and federal government of the United States (Burby, 2001). The Federal Insurance Administration (FIA), which is part of the Federal Emergency Management Agency (FEMA), identifies flood hazard areas with so-called flood insurance rate maps (FIRM) and establishes criteria for constructions in these floodplains. Thereby, state governments authorize and support local governments in establishing regulations. The aim of the NFIP is to slow down intensive urbanization in areas at high flood risk and to help local authorities to steer development mainly towards safer zones and take measures to mitigate damage (Burby, 2001). Burby (2001) identified the need to map flood hazards in adequate detail to determine the exact insurance rates and to raise public awareness of flood risk.

In Europe, flooding has become increasingly important for citizens, insurance companies and authorities (van Alphen et al., 2009). The increasing number of severe floods has triggered the request for a new approach to flood risk mapping and management (van Alphen et al., 2009). On October 23, 2007, this request resulted in the European Floods Directive (2007/60/EC) that obliges the Member States of the European Union (EU) to create flood risk management plans (Hartmann & Juepner, 2017). The aim of the EU Flood Risk Directive is to develop a framework for the assessment and management of flood risk that reduces the consequences of floods for human health, the environment, cultural heritage and the economy (Tsakiris et al., 2009). The Flood Risk Directive is divided into three stages (Dráb & Říha, 2010):

1) Preliminary flood risk assessment
2) Creation of flood hazard and risk maps for various scenarios
3) Development of flood risk management plans

In a first step, EU Member States have to implement a preliminary study for flood risk assessment by 2011 in order to identify areas where there is a significant flood risk. Afterwards, Member States have to prepare flood hazard and risk maps for the assessed areas by 2013. In a final step, flood risk management plans must be drawn up on the basis of the risk zones defined in the second step. The primary focus of the flood risk management plans is on prevention, protection and preparedness (Tsakiris et al., 2009). However, the three stages are only the mandatory steps and do not specify a common method for the design of a flood map (Dráb & Říha, 2010). In general, there is a lack of widely accepted methodologies which leads to different implementations of flood maps, as will be shown in chapter 2.2.2 (Tsakiris et al., 2009).

These two examples of the USA and Europe show the importance of dealing with the increased flood hazard by means of flood maps as recognized by federal governments and supranational organizations. In addition, the question regarding the design of flood maps is still unclear nowadays and seems to be more important than ever because of the role of flood maps in risk communication. Thus, flood visualizations are united in the goal, but differ in method and design.

2.2.2 Types of flood maps

A flood mapper can use various parameters to denote flood hazard and risk. The most typical flood parameters are flood extent, water depth, flow velocity, duration, propagation of waterfront and water-rise rate (De Moel et al., 2009). This diversity of parameters leads to a wide range of different types of flood maps. Figure 1 shows a conceptual framework for flood hazard and risk calculation (De Moel et al., 2009). Based on this framework, an overview of the different types of flood maps is given in Figure 2 and each one of them is briefly explained and discussed according to the state of research.

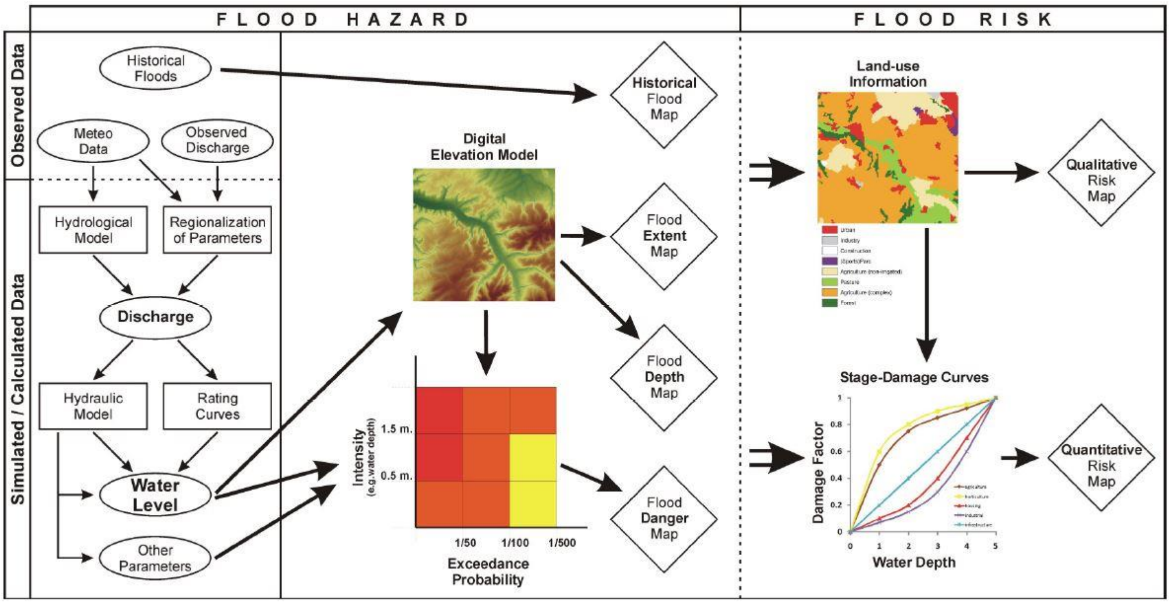

Figure 1: Conceptual framework for different types of flood maps (De Moel et al., 2009)

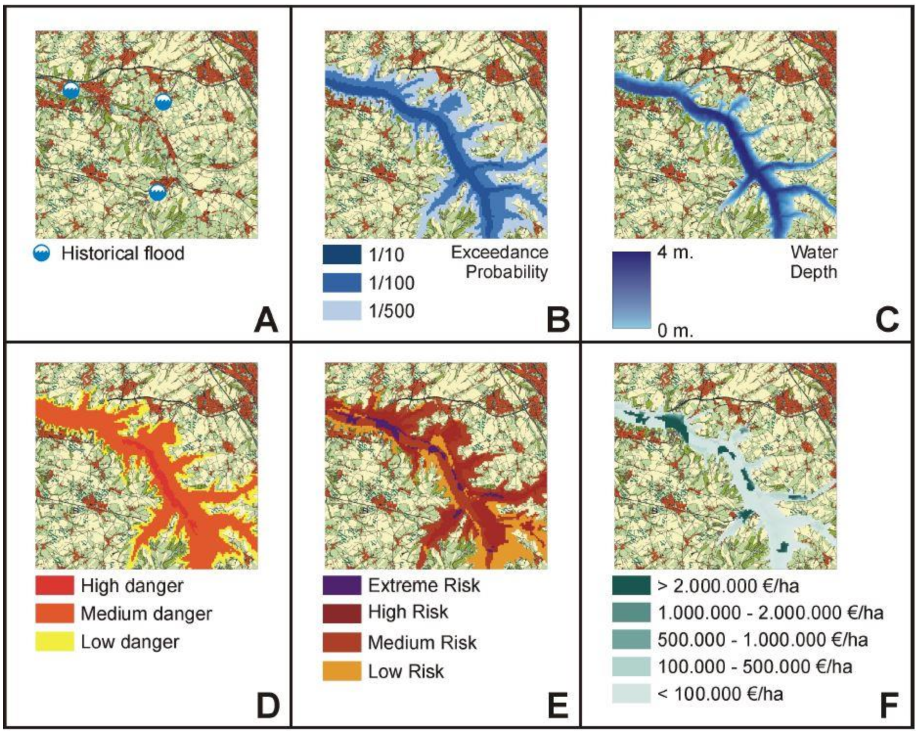

Figure 2: Different types of flood maps (A) Historical flood map, (B) Flood extent map, (C) Flood depth map, (D) Flood danger map, (E) Qualitative flood risk map, (F) Quantitative flood risk map (De Moel et al., 2009)

Historical Flood Map

A very first statement for the assessment of a flood hazard can be made by looking at how often and to what extent floods have occurred in history. The information about frequency and extent of historical flood events can be visualized as points (Figure 2A) or as polygons, representing the spatial extent (Figure 2B). However, what happened in the past will not necessarily happen to the same extent in the future. In addition to this, it is also impossible to compare historical with potential future events, since conditions such as land cover or new flood protection infrastructure can change significantly over time (De Moel et al., 2009).

Flood Extent Map

Flood extent maps, as shown in Figure 2B, are the most common flood hazard maps. They display the spatial extent of a specific flood event with a particular return period (e.g. once every 100 years). The data can be based on historical events or based on hypothetical floods with simulated respectively calculated data. In addition to the specified water level, a digital elevation model (DEM) is required to consider the topography. Flood extent maps are often visualized with additional information by highlighting important exposed infrastructures (e.g. hospitals, schools) or with points indicating flood depth or velocity. With the help of these maps, the flood extent can be easily visualized and thus, provides a good overview of the situation without adding too much flood parameters and information (De Moel et al., 2009).

Flood Depth Map

The statistically modelled water levels combined with a DEM cannot only be used to calculate the flood extent for specific return periods, but also to display flood depths (Figure 2C). For a general overview of the flood hazard, flood depths can be visualized as a raster dataset showing depth values per pixel (De Moel et al., 2009). Flood depth maps are intuitive to read and raise risk awareness among the public.

Flood Danger Map

Flood depth is not the only parameter determining how threatening a flood is. Different parameters such as velocity, duration, propagation and water-rise rate are also important when mapping flood hazards. Instead of overloading the flood map with information, the parameters can be aggregated into qualitative classes such as “low danger”, “medium danger” and “high danger” (Figure 2D). The aggregation process of different parameters is often performed by using matrices. The two axes of a matrix can be two different flood parameters (e.g. depth, velocity) or already grouped parameters (e.g. intensity as a result of depth and velocity) (De Moel et al., 2009). Flood danger maps with their qualitative classification are easy to understand for the public and quite popular in use. Figure 3 shows the matrix which is used to determine the danger levels in Switzerland. Spatial planning and building regulations often refer to these levels (van Alphen et al., 2009).

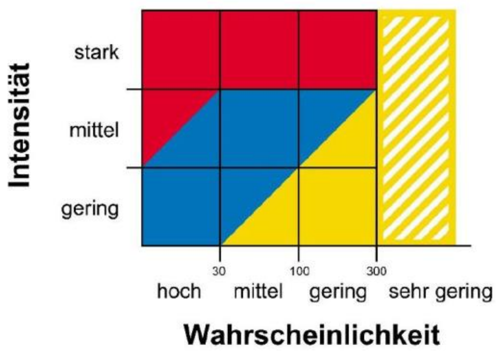

Figure 3: Danger matrix Switzerland (BAFU Abteilung Gefahrenprävention, 2015)

Areas with low risk are assigned to the yellow zone. In those areas, the flood intensity and also the probability of a flood is low and new buildings can be built if they are informed about the danger (BAFU Abteilung Gefahrenprävention, 2015). The blue zone represents a medium danger for which enforced construction of buildings are necessary. New developments are prohibited in the red zone due to the high risk (van Alphen et al., 2009). However, different danger matrices or danger levels respectively are often not comparable because they are based on different classification approaches (De Moel et al., 2009).

Flood Risk Map: Qualitative and Quantitative

Flood risk is defined as the combination of the probability and extent of damage of a flood event. Thus, a flood risk map visualizes the hazard information in combination with additional information on the consequences of a flood. A flood risk map can be qualitative or quantitative, depending on the characteristics of the indicators (De Moel et al., 2009). For instance, economic consequences are mainly quantifiable indicators whereas health or ecological damage is difficult to quantify. Figure 2E shows a qualitative flood risk map. It visualizes the potential damage, classified in a range from "low risk" to "extreme risk" of an area for a particular event. It differs from a flood danger map as it does not deal with hazard levels but with risk levels. For example, a qualitative flood risk map takes into account the qualitative extent of damage as an additional information, whereas a flood danger map is usually a product of calculated flood intensity and probability. Figure 2F is an example of a quantitative flood risk map which indicates the potential costs per hectare caused by a certain flood event. However, the calculation of the costs still contains uncertainty. Thus, maps visualizing absolute damage information should be interpreted carefully. Nevertheless, flood risk maps are important for the support of decision makers. They might show decision makers concentrated areas that require additional protection (van Alphen et al., 2009). However, it is difficult to consider flood risk maps as homogeneous. Especially due to the various indicators that summarize the damages caused by a flood, flood risk maps can be regarded as less homogeneous than flood hazard maps (De Moel et al., 2009).

This subchapter has shown that there are many different 2D flood map types and designs. The next subchapter presents the current state of research regarding recommended designs and visualization characteristics of 2D flood maps.

2.2.3 Flood map designs and guidelines

As the NFIP and the European Floods Directive have shown, a flood hazard or risk map is the basis for spatial planning, local hazard assessment, determination of insurance rates and emergency planning. However, in order to avoid errors or distortions, efficient color maps and the choice of a suitable type of visualization are important for risk communication (Seipel & Lim, 2017). A well-designed flood map results in a higher awareness and in growing interest for users (Hagemeier-Klose & Wagner, 2009). However and according to Fuchs, Spachinger, Dorner, Rochman, & Serrhini, (2009), there is still little information available about the important aspects of design and how the flood maps are most effective for risk communication and decision making.

Since flood hazard maps are the basis for many disciplines and user groups, they have to fulfil various demands. In their user study, Hagemeier-Klose & Wagner (2009) conducted a creative workshop to discuss imaginary and existing flood hazard maps. Participants mainly preferred flood hazard maps which are (1) easy to understand, (2) clearly arranged and (3) accompanied with simple explanations (Hagemeier-Klose & Wagner, 2009).

In terms of (1) easy to understand, flood hazard and risk maps should be intuitive and should meet the reader's expectations. From a visual point of view, blue as the associated color for water should be used for floodplains in flood hazard maps (Hagemeier-Klose & Wagner, 2009). Informal interviews with students also resulted in blue as the intuitive color hue for flooding conditions (Seipel & Lim 2017). Color is very powerful as a visual variable (Seipel & Lim, 2017). By its nature, color has three dimensions: hue, saturation and lightness. These three dimensions can be altered to represent quantitative information (Seipel & Lim, 2017). Fuchs et al. (2009) recommended to use red hues especially for visualizing risks rather than flood depths. Van Alphen et al. (2009) mentioned in their article that red, orange and green are associated with danger, attention and safety. Furthermore, a digital city plan or an orthophoto should be used as a background map to facilitate orientation and assessment of the extent (Hagemeier-Klose & Wagner, 2009). In the analysis of Fuchs et al. (2009), 45% of their participants preferred an orthophoto, while around 50% preferred a land plan as a background map. Nevertheless, the map background should be presented in light colors to increase the contrast to the information content and to avoid an information overload (Fuchs et al., 2009). Additionally, flood hazard maps are the kind of visualizations that imply a crisp border of regions with potential floodplains and safe areas. However, all spatial data on which we base our space-time decisions are affected by uncertainty (Duckham, Mason, Stell, & Worboys, 2001). It can be problematic if map readers consult flood hazard maps under the assumption that they do not contain uncertainties (Seipel & Lim, 2017). There are studies on how to visualize uncertainty, how uncertainty influences the process of decision making and the outcome of different visualizations of uncertainty (Kübler, Richter, & Fabrikant, 2019; Ruginski et al., 2016; Seipel & Lim, 2017). However, uncertainty visualization will not be discussed in more detail, as this would go beyond the scope of this work.

Flood hazard and risk maps should also have a (2) clearly arranged layout (Hagemeier-Klose & Wagner, 2009). In their study to find the most attractive components for communication of cartographic information, Spachinger et al. (2008) suggested a map layout template. The most attractive map components were identified with the eye-tracking method accompanied by a survey and was used to study the reading behavior of the participants (Fuchs et al., 2009; Spachinger et al., 2008). The generated map template of Spachinger et al. (2008) is shown in Figure 4 and aims to serve as an efficient communication tool for the public and for specialists.

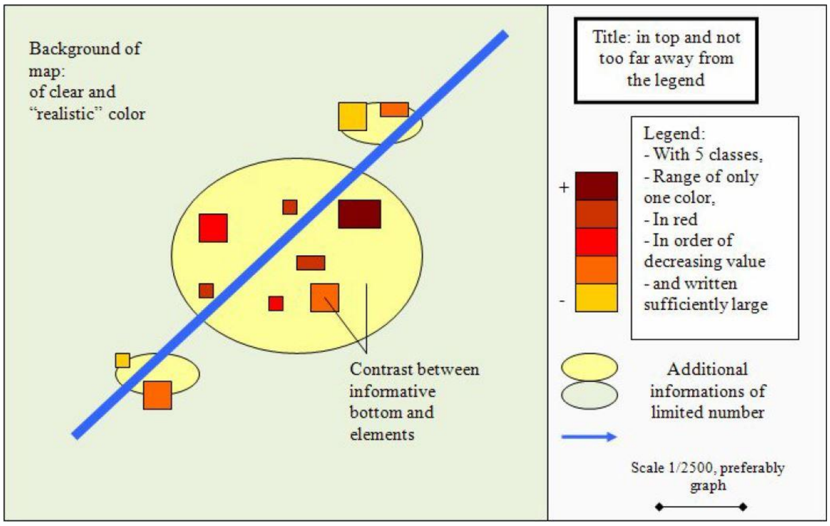

Figure 4: Map template based on results of an eye-tracking and qualitative study (Spachinger et al., 2008)

Spachinger et al. (2008) concluded in their study that 75% of their participants preferred the legend on the right side and 70% favored the title in the upper part above the legend. Thus, with an appropriate contrast, title and legend fulfil its informative function best when located on the right side of the map (Fuchs et al., 2009). Figure 5 shows a representation of the resulting visual strategy when using this map template. Firstly, the eye focusses on the center of the map, where only necessary information should be highlighted. Only in a second step, the eye moves to the title and legend. After gathering the textual information, the eye returns back to the central element of the map and explores peripheral elements as well (Fuchs et al., 2009; Spachinger et al., 2008). In the case of flood hazard and risk maps, this layout should ensure a clear arrangement that helps to fulfil the demand of the different map-readers.

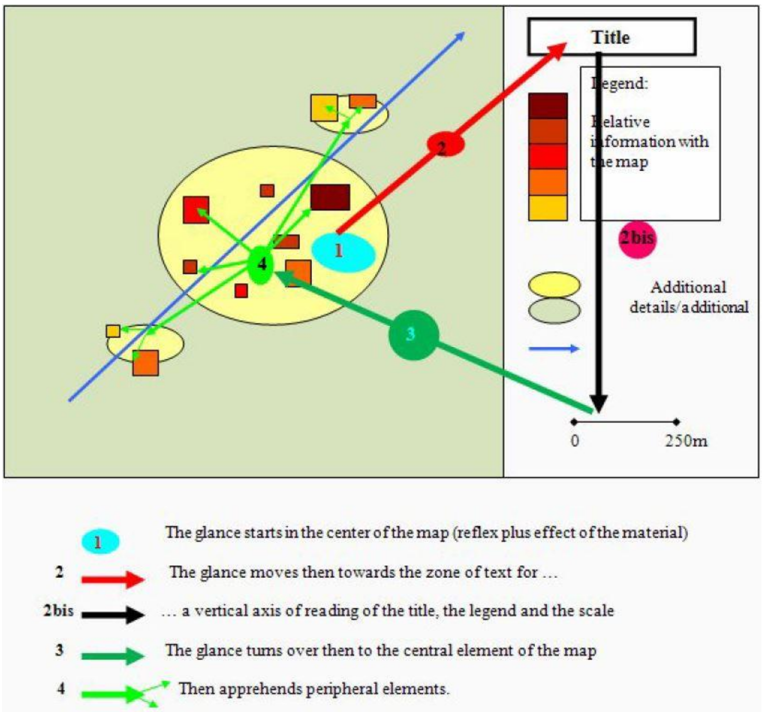

Figure 5: Map reading strategy recorded by an eye-tracker (Spachinger et al., 2008)

Last but not least, the study by Hagemeier-Klose & Wagner (2009) mentioned that (3) simple explanations are also important to provide an efficient risk communication. Especially the public is one of the most important map-readers due to their direct involvement in flood events and damages. Since the majority of the public are not experts in map reading, it is important to keep the visualization simple. Fuchs et al. (2009) and Spachinger et al. (2008) recommended a "sufficiently large legend with conservative amount of information (five classes of discretization) comprised from one color range". Both authors clearly advocate a discrete representation, although many flood parameters such as water depth and flow velocity are continuous phenomena. However, other researchers emphasize that a continuous visual representation is a good choice for a continuous parameter (Padilla, Quinan, Meyer, & Creem-Regehr, 2017). But in practice, there are a lot of domains (e.g. meteorology), which visualize continuous data with a discrete encoding (Padilla et al., 2017). Padilla et al. (2017) conducted a study which showed that participants with continuous visualizations seem to complete tasks quicker, but the accuracy in performance was superior using discrete visualizations in some of the tasks. It can be argued that accuracy is more important than response time when assessing the flood hazard and thus, a discrete representation is an appropriate choice to keep the visualization easy to read. A further point to consider is to minimize the information wherever possible and only highlight the necessary information with sufficient contrast (Fuchs et al., 2009). For instance, the water flow velocity should not be integrated into a public map because this information is not frequently used by the public (Hagemeier-Klose & Wagner, 2009). As a last point, technical terminologies should be avoided if possible. For example, HQ100 is often used as a term for the hundred-year flood, which is a flood event with a medium probability. Both terms, HQ100 and hundred-year flood can lead to confusion and let laypersons believe that such a flood event can only occur once every 100 years.

2.3 Flood visualizations in 3D

As mentioned earlier in this work, flood risk communication is becoming more and more important as the frequency of flood events increases due to climate change and the gradually increasing number of buildings in floodplains due to urban sprawl (Zhi, Liao, Tian, & Wu, 2020). However, not only urbanization and the frequency of flood events are increasing but also the possibilities offered by new technologies. Firstly, this chapter provides a general overview of alternative visualization techniques and their history. Secondly, some advantages and pitfalls of visualizations using the third dimension in relation to flood hazard and risk are explained and concluded with some practical examples.

2.3.1 The third dimension

The last quarter of the last century was dominated by "a wealth of experimentation in 3D data visualization" (Shepherd, 2008). Developments in computer hardware and software made it possible to fully use 3D spatial information in visualization technology (Zhi et al., 2020). Already in 1969, Sutherland tested a head-mounted 3D display device (HMD) (Sutherland, 1968). The use of 3D GIS was recognized as a promising topic and progress was made in its development in the late 1980s (Raper, 1989). Due to lower prices for graphics display technology in the 1990s, interactive 3D computer graphics and as a consequence, various visualization techniques became more popular and widespread (Shepherd, 2008). In this subchapter, a selection of the most popular alternative visualizations (static and interactive 3D visualizations, augmented and virtual reality) is given in comparison to classical 2D flood visualizations presented before. The comparison is focused mainly on differences in visualization characteristics. This subchapter does not compare the alternative visualizations with the 2D flood maps with respect to efficiency and user behavior, because the state of research on this topic is presented in chapter 2.4.

Static and interactive 3D visualizations

In addition to traditional 2D maps, 3D visualizations are becoming a gradually increasing part of our everyday life and thus, alternative visual perspectives are getting more and more important as technology evolves (Philips et al., 2015).

Although we assume that the origin of the growing possibilities to create 3D visualizations lies in the technological progress, the first maps were actually already drawn in a perspective way. Figure 6 shows the map of Mesopotamia, one of the first known maps that dates from 5.000 years b.c. (Petrovič & Mašera, 2007).

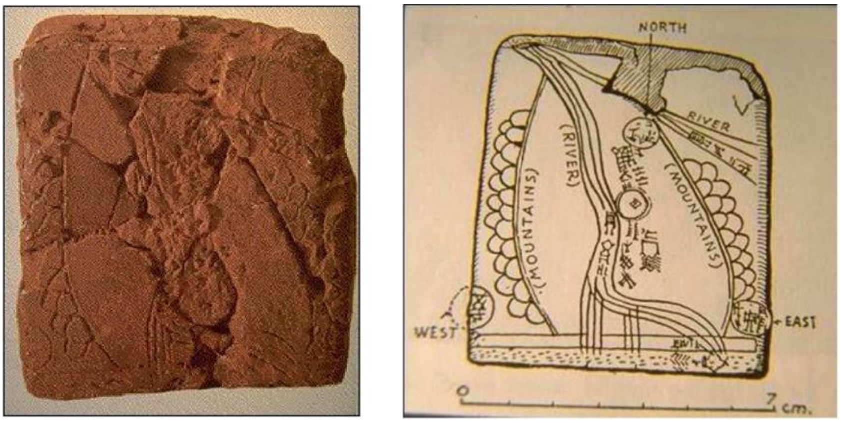

Figure 6: Map of Mesopotamia with mountains in an oblique perspective (Petrovič & Mašera, 2007)

The map of Mesopotamia has two different perspectives. A major part of the content is presented with an orthogonal perspective, but mountains are mapped in an oblique perspective. Petrovič & Mašera (2007) stated in their article that through the human history, cartographers wanted to visualize the topography as realistic as possible by using oblique perspectives to achieve this effect. Only in the last 200 years, orthogonal perspective or the so-called ground plan maps with their indirect way of relief visualization (hatching, contours) were dominant (Petrovič & Mašera, 2007).

The third dimension has the significant advantage to display an additional variable (Kraak, 2003). But what happens when another dimension is added to a map? Figure 7 shows the well-known map “Napoleon’s March on Moscow” by Charles Minard from 1861. This map visualizes the losses of the Napoleonic army during his Russian campaign with several variables in a two-dimensional plane.

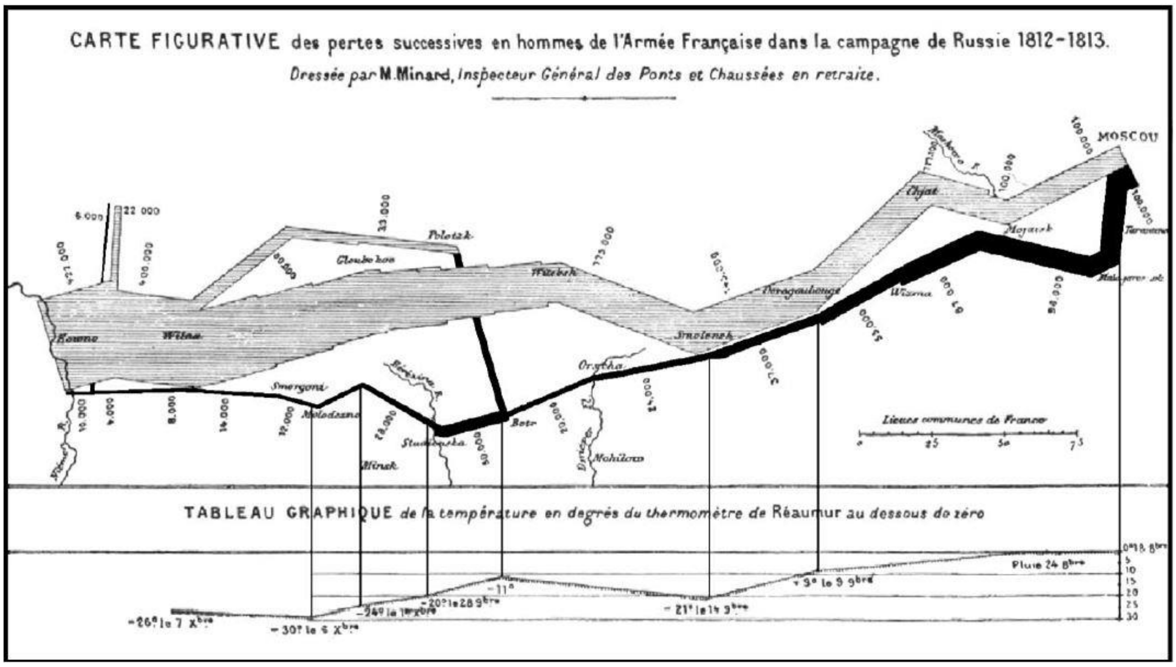

Figure 7: Charles Minard's map from 1861: "Napoleons March on Moscow" (Kraak, 2003)

Firstly, the location is represented with the two major bands and some minor paths. Secondly, the black and solid path directing backwards is linked to a temperature diagram. Thirdly, the diagram presents the size of the army by the width of the bands. Time is constituted as the hatched "going east" band and the black "going west" band. To come back to the question what happens when an additional dimension is added, a possible result is presented in Figure 8 (Kraak, 2003).

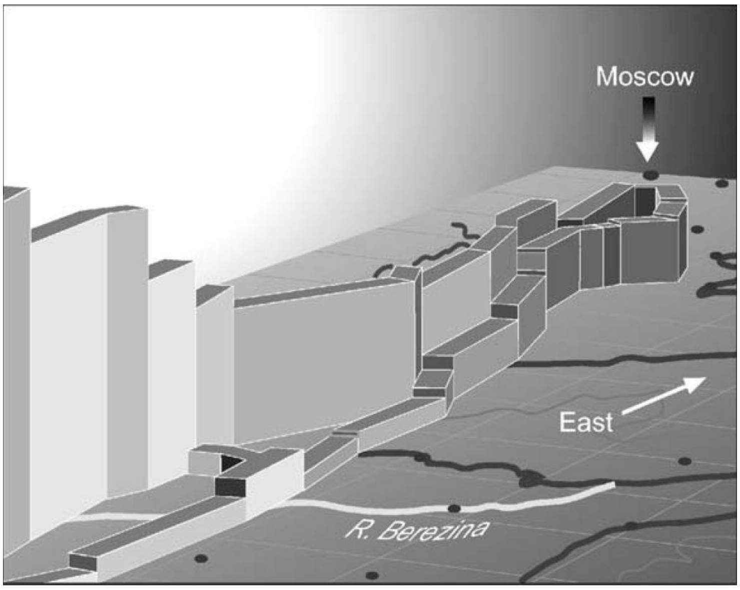

Figure 8: 3D-view of the size of Napoleon's troops during the Russian campaign (Kraak, 2003)

In this figure, the height of the path segments shows the number of troops (Kraak, 2003). This information is also represented in the original 2D map in Figure 7 by the width of the paths, but according to Kraak (2003) it seems to look more dramatic in the 3D display. Thus, can an additional dimension let appear a visualization more dramatic? What does that mean for the mentioned visual risk communication? This question is discussed in more detail in the chapter 2.4. For the understanding and communication of flood risk to the public, the practitioners and decision-makers seem to be no longer able to avoid the topic of 3D visualizations (Macchione et al., 2019).

On a micro-scale, 3D spatial information of buildings such as the level of water immersion relative to their height is considered as an important impact on urban flood risk management (Zhi et al., 2020). In other words, Zhi et al. (2020) combined the change in height of water with the 3D buildings to get the flood ratio of buildings relative to their height. Amirebrahimi, Rajabifard, Mendis, & Ngo (2016) also recognized the importance of visualizing buildings in flood risk management. They identified possible reasons in the significance of buildings for the economy and because of their large share in the total flood damage bill. Thus, Amirebrahimi et al. (2016) designed a tool for a detailed assessment of flood risk to proposed buildings. The results of the study showed that floods could be visualized in 3D for a micro-scale purpose as Figure 9 indicates (Amirebrahimi et al., 2016).

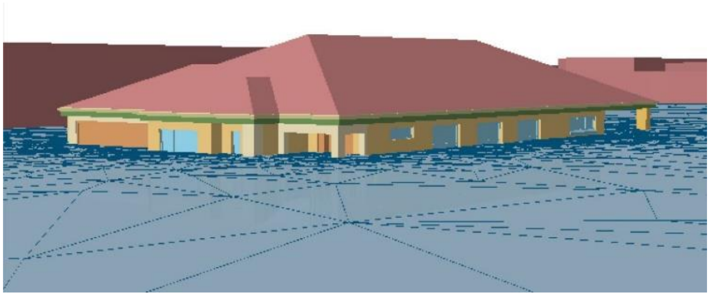

Figure 9: 3D flood surfaces around a building (Amirebrahimi et al., 2016)

However, 3D flood visualizations are not limited to the micro-scale. Evans et al. (2014) created a 3D flood visualization for the Thames River in the Thames Valley, UK over a length of 40km. The aim was to raise risk awareness for potential future flood events. In chapter 2.3.3, this example is described in more detail.

Furthermore, 3D visualizations do not have to be static. Due to the above mentioned improvements in computer technology, a wide spread of spatial data in the public through globe viewers, such as Google Maps, has taken place (Zanola, Fabrikant, & Cöltekin, 2009). Such interactive 3D geo-browsers are becoming more popular because they are user-friendly (Wilkening & Fabrikant, 2013).

Augmented Reality

Another result of the rapid technological progress in computer technology is found in the augmented reality (AR) technology and more recently in the Mobile AR (MAR). AR technology enables the user to see virtual elements in physical reality through a camera (Hincapié, Caponio, Rios, & González Mendívil, 2011). AR is mainly applied on mobile applications and has been used more frequently in recent years (Mirauda, Erra, Agatiello, & Cerverizzo, 2018). A major strength of AR is that it allows the user to perceive the data in the physical surroundings and to explore the relations between them (Mirauda et al., 2018).

Haynes, Hehl-Lange, & Lange (2018) recognized the new offered levels of engagement by linking simulations with on-site experience. In their paper, they present a real time immersive prototype MAR app for flood visualizations (Haynes et al., 2018). Besides the development of the MAR app, understanding the experts' opinion was a major goal of their study. Figure 10 shows the browser-mode of the app in which the flood is presented as a blue plane that can be levelled up and down by sliding with the finger in order to simulate a potential flood.

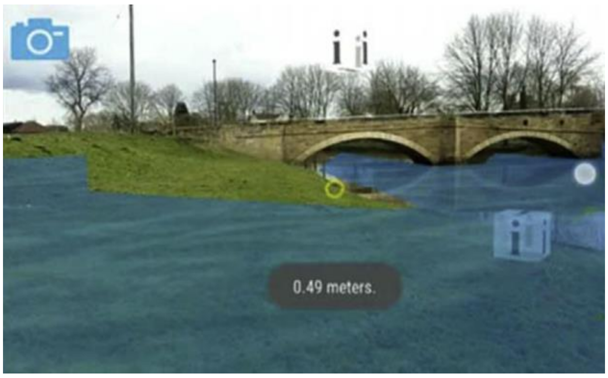

Figure 10: Flooding in an AR application (Haynes et al., 2018)

Experts found the app useful, especially for emergency services. This conclusion confirms the results of previous studies in which user preferences for immersive 3D visualizations were determined (Gill & Lange, 2015).

Virtual Reality

A further visualization technology is constituted in virtual reality (VR). In contrast to AR, where virtual elements are projected onto the physical world in situ, VR is a complete virtual immersion in a 3D environment (Philips et al., 2015). VR is very popular due to the gaming industry with its increasing complex immersive environments (König et al., 2020). Virtual environments support the investigation in many research fields, such as spatial navigation and controlled spatial learning (Credé, Thrash, Hölscher, & Fabrikant, 2019; König et al., 2020; Philips et al., 2015).

With regard to flood risk management, VR can be used as a training tool for disaster preparedness and response activities (Sermet & Demir, 2019). Sermet & Demir (2019) designed a VR game called "Flood Action VR" with various tasks that need to be solved during a disaster event. The players are pressed for time so that they have to make decisions under stress. A screenshot of the Flood Action VR is presented in Figure 11.

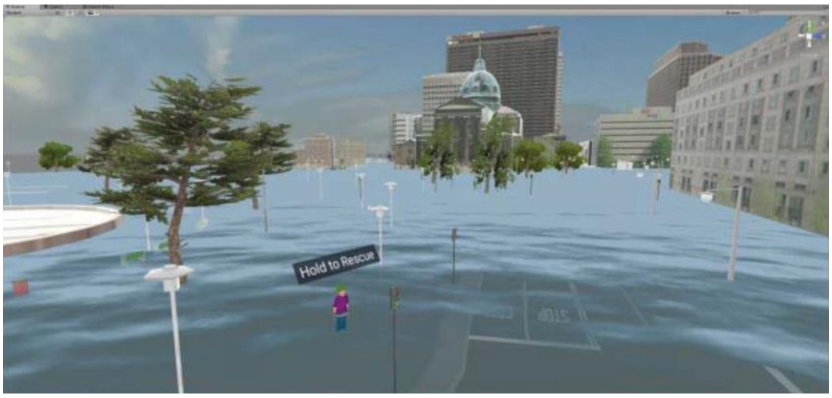

Figure 11: Screenshot from Flood Action VR (Sermet & Demir, 2019)

Based on its real-world data and scenarios, Flood Action VR can be used as an educational tool for college level students or also as a decision support tool for disaster preparedness purposes (Sermet & Demir, 2019).

2.3.2 Visualization characteristics of static 3D visualizations

Out of the presented alternative visualization techniques using the third dimension in the previous section, this subchapter mainly focuses on the visualization characteristics of static 3D visualizations because this type of visualization is a major part of the thesis. In this chapter, some advantageous and disadvantageous visualization characteristics of static 3D visualizations in general are explained. While this chapter focuses on the differences of visualization characteristics between 2D and 3D, chapter 2.4 focuses more on the differences in human perception between the two visualization types.

Visualization characteristics of static 3D visualizations: Benefits and pitfalls

In general, there seem to be some good reasons to use a third dimension in visualizations. 3D computer graphics became very popular and widely available in the 1990s and it is getting easier to implement and distribute visualizations with a third dimension (Shepherd, 2008). A highly advantageous point is that we can represent 3D features of the real world as 3D objects. This seems to make life easier for occasional map users, as they do not have to encode abstract symbols (Shepherd, 2008). Thus, the 3D visualization has the visual characteristic to be closer to our real world. As a second advantageous attribute, a 3D visualization allows to display an additional variable (Shepherd, 2008). For example, in addition to information about the location of a building, which is described with x and y coordinates, the height of the building can be represented with an additional z value. This intuitive example shows that a 3D visualization permits a larger amount of information to be displayed. Thus, 3D visualizations can convey more information because of less abstraction (Fabrikant, Maggi, & Montello, 2014). However, Shepherd (2008) emphasized that it is important to reflect also about some less favorable attributes that might occur when using 3D visualizations. Most 3D scenes are in an oblique perspective and the scale variation makes it difficult to do accurate visual comparisons of features (Shepherd, 2008). This scale variation manifests itself in our perception in a way that closer objects seem to appear larger than distant objects because the scale is not uniform over the line of sight (Biljecki et al., 2015). As a result, a 3D visualization is a map without a fixed scale (Niedomysl et al., 2013). Another quite impacting pitfall of most 3D visualizations is the suffering from symbol occlusion (Shepherd, 2008). Depending on the user's viewpoint, some smaller objects in the background are hidden by larger objects in the foreground (Niedomysl et al., 2013). Also Zhu & Chen (2005) emphasized this issue when only a single point of view in a 3D visualization is provided. A further famous drawback of static 3D visualizations is presented in the symbol viewpoint dependencies (Shepherd, 2008). A static 3D visualization is tilted with a certain angle and depending on this angle, the same object can appear shorter or longer in the vertical dimension (Niedomysl et al., 2013). Table 2 summarizes the most important advantages and disadvantages of static 3D visualizations.

Table 2: Advantages and disadvantages of static 3D visualizations

Advantages	**Disadvantages**
Close to the real world (less abstraction needed, users can easily understand elevation differences) (Fabrikant et al., 2014; Petrovič & Mašera, 2007; Schobesberger & Patterson, 2008; Shepherd, 2008)	Scale variation (Fabrikant et al., 2014; Niedomysl et al., 2013; Petrovič & Mašera, 2007; Schobesberger & Patterson, 2008; Shepherd, 2008)
Displaying additional data variables (Fabrikant et al., 2014; Petrovič & Mašera, 2007; Shepherd, 2008)	Symbol occlusion (Fabrikant et al., 2014; Niedomysl et al., 2013; Petrovič & Mašera, 2007; Schobesberger & Patterson, 2008; Shepherd, 2008; Zhu & Chen, 2005)
Eye-catching (Schobesberger & Patterson, 2008; Shepherd, 2008)	Symbol viewpoint dependencies (Fabrikant et al., 2014; Niedomysl et al., 2013; Shepherd, 2008)

However, there are some solutions to avoid or bypass scale variation, symbol occlusion and symbol viewpoint dependencies in 3D visualizations. For example, Shepherd (2008) suggests using non-perspective projections that makes it easier to compare the symbol sizes across the scene. An intuitive solution to avoid symbol occlusion is to transform the 3D visualization in an interactive scene. Then, the users have the ability to rotate or move their viewpoint with respect to the scene and bypass the occlusion problems (Shepherd, 2008). Symbol transparency, object displacement or view distortion (e.g. fish-eye view) are also potential solutions (Shepherd, 2008). To avoid symbol viewpoint dependencies for the most part, an appropriate choice of angle should be considered. For instance, 3D objects with minimal thickness would completely disappear when viewed from the side (Shepherd, 2008).

3D visualization characteristics: Level of detail

Another important aspect is the level of detail (LOD) of a 3D visualization. The LOD "defines the degree of abstraction of real-world objects, primarily designated to use an optimum amount of details according to the user's needs" (Macchione et al., 2019). The brief presentation of the concept of LOD's is important for this work because buildings are relevant objects in 3D city models or flood visualizations. In general, there are five different levels of details (LOD 0-4) defined by the open standardized data model CityGML (Macchione et al., 2019). They differ mainly in the complexity of their geometries as shown in Figure 12 on the next page. A LOD 0 is basically a 2D map with a 3D terrain. LOD 1 are box models, whereas in LOD 2 the box models are supplemented by a roof structure. Features such as balconies and openings are part of the LOD 3 models. Last but not least, LOD 4 models even consider building interior features and are, therefore, the most complex models (Deng, Cheng, & Anumba, 2016). Different visualization purposes and target audiences requires different LOD's. For example, Macchione et al. (2019) used a LOD 1 model for their flood simulation in Cosenza, Italy (see following chapter 2.3.3). However, when more detailed information about the influence of a potential flood is needed, the LOD 1 buildings with their solid vertical walls, obtained by extrusion of the footprint, seem to be not sufficient. In this case, a house model with more complex geometry (openings, balconies etc.) and texture is probably better suited.

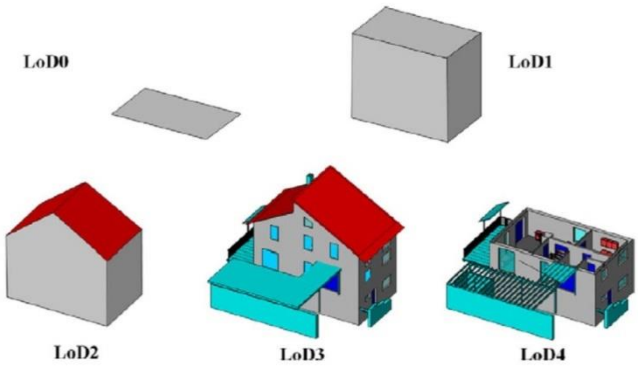

Figure 12: LOD's in CityGML (Deng et al., 2016)

The influence of different level of realism on the user is discussed in academic works. Klausener (2012) investigated in her master thesis the effect of different levels of realism on our acceptance of building projects. She noted that the acceptance is more likely to be reduced with decreasing realism. Thus, the level of realism in 3D visualizations might have an influence on people's confidence in a project's quality or in spatial data quality in general (Zanola et al., 2009).

2.3.3 Examples

After providing an overview over some advantageous and disadvantageous visualization characteristics of 3D visualizations including LOD's, this subchapter gives examples of existing 3D flood visualizations. The previous theoretical inputs on the visualization characteristics of 3D visualizations and LOD's will be taken into account while presenting the examples.

Evans et al. (2014) explored the future application of 3D flood visualization in flood risk management and created 3D flood visualizations for five locations in the UK: Exeter, Durham, Grimsby, Whittlesey and the Lower Thames Valley. Figure 13 shows the result for Exeter.

Figure 13: 3D flood visualization of Exeter, UK (Evans et al., 2014)

The visualization is shown in oblique perspective in order to give a 3D effect and to enable the public to capture the impact of that particular flood event (Evans et al., 2014). Together with a detailed and realistic representation of muddy water, this example shows the beneficial attribute of a 3D visualization to provide a familiar view of the world. Furthermore, the height information given by the oblique perspective makes it easier to interpret which infrastructure is more affected by the flood. If one wants to measure the accurate spatial extent of the flood, it is probably difficult with a static image like this one, since the scale varies with increasing distance from the user's viewpoint. For example, it is difficult to estimate the flood extent behind the soccer field compared to the flood in the foreground. Additionally, from this user's viewpoint some symbol occlusion can be observed as some houses are hidden due to other buildings in the foreground. The buildings were equipped with a roof structure (Evans et al., 2014). Thus, the 3D visualization represents at least a LOD 2. Since especially some bigger buildings show some exterior features, it can be assumed that it is even LOD 3. This visualization was used to present an efficient way to engage the public on flood hazard issues through 3D flood visualizations. It is an effective way because according to Evans et al. (2014), it seems to reduce the cognitive effort people have to bring up for interpreting the map or a complex model.

Another example is presented in the paper of Macchione et al. (2019). The study area is Cosenza (Italy), a town where the urban area is located at the confluence of two rivers. Macchione et al. (2019) recommend 3D flood visualization as a new platform to communicate risk and, therefore developed a workflow for the visualization of hydraulic simulations in a 3D environment. A texture mapping technique is also part of the workflow to let appear the building facade more realistic. The visualized flood extent is a hypothetical flood with a return time of 500 years (Macchione et al., 2019). Figure 14 shows an example of the resulting 3D visualization.

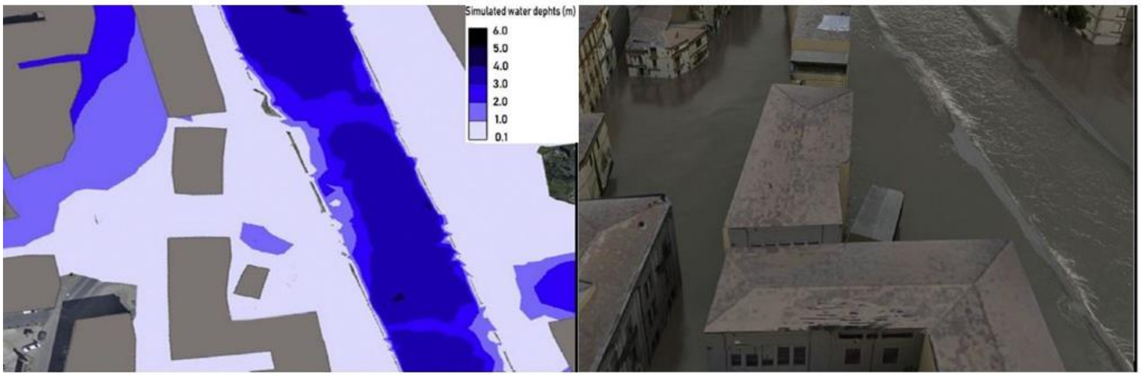

Figure 14: 3D flood visualization of Cosenza, Italy (Macchione et al., 2019)

According to Macchione et al. (2019), the purpose of using 3D flood visualization in risk communication is to improve the readability and usability of hazard maps for the public. As Evans et al. (2014) mentioned, the 3D visualization makes it easier for a non-expert audience to evaluate the consequences of a flood event. As in the example of Evans et al. (2014), the authors decided to improve the realism of the cubic building polygons by inserting texture on the facades. Although a certain degree of realism is added, Macchione et al. (2019) emphasized that balconies, bows, openings etc. are still absent in the 3D visualization compared to the real world. Furthermore, the buildings are cubic, although the texture mediates a roof structure. Thus, this 3D model can be characterized as a visualization of a LOD 1.

Despite these examples, 2D visualizations are still the standard to convey flood hazard information although 3D visualizations are well established in today's society. While this chapter focused mainly on the differences in visualization characteristics between 2D and 3D, the next chapter will focus more on the state of research about the differences between 2D and 3D in terms of the influence on our risk perception.

2.4 2D vs. 3D

According to Rollason, Bracken, Hardy, & Large (2018), existing research recognizes a limited impact of current flood risk communication on risk awareness. In the UK, only 45% of people living in risk areas assess their risk and only 7% identify a risk to their own property (Environment Food and Rural Affairs Select Committee, 2016). It seems that current 2D flood maps do not fulfill the task of raising flood risk awareness. Some researchers stated that a more effective communication can be achieved with 3D visualizations (Kemec et al., 2010; Leskens et al., 2017; Macchione et al., 2019).

This chapter first combines the knowledge presented in chapters 2.2 and 2.3 by giving an overview over the current state of research whether 2D or 3D visualizations are generally more effective in risk communication. Secondly, it presents some studies that have investigated the map users' preferences related to this question. Thirdly, and to be more specific on flood hazard visualizations, the academic discussion on whether 2D or 3D is more appropriate to communicate flood risk is presented.

2.4.1 Overall discussion

Nowadays, the question whether to use 2D or 3D visualizations is asked more and more frequently (Dübel, Röhlig, Schumann, Trapp, & Schumann, 2014). Map technicians are therefore confronted more than ever with a number of choices for the use of visualization techniques (Dübel et al., 2014). With the technological advances, a bigger enthusiasm for 3D visualizations is recognized, as we can display more information and less abstraction is needed by reducing high dimensions into 3D rather than 2D (Fabrikant et al., 2014). However, Fabrikant et al. (2014) mentioned that a 3D visualization with its additional supply of information has its disadvantages (see chapter 2.3.2) and that cognitive demands and technological requirements can increase with a third dimension. Not surprisingly, there seems to be no research that has clearly identified 3D visualizations as superior.

I want to present some empirical studies, which investigated the performance of 2D and 3D visualizations in general. Savage, Wiebe, & Devine (2004) conducted a study between 2D and 3D topographic representations, in which participants had to solve different tasks. The tasks were distinguished in elevation tasks and non-elevation tasks and the aim of the study was to investigate whether 3D topography had the advantage for shape understanding compared to the traditional 2D map. Figure 15 shows two tasks (elevation and non-elevation task) of the study.

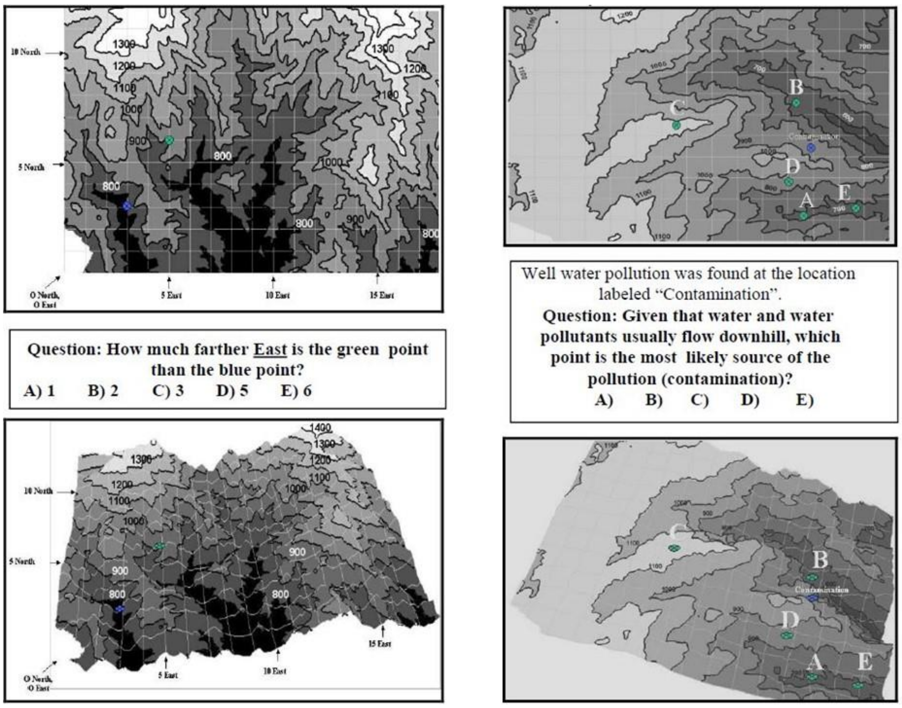

Figure 15: 2D or 3D: Non-elevation task (left) and elevation task (right) (D. M. Savage et al., 2004)

Participants were randomly assigned to either 2D or 3D visualizations. As a result, there was found a significant accuracy and time advantage for 2D visualizations in non-elevation tasks (e.g. a task such as on the left of Figure 15). Even for tasks requiring elevation information, there was neither an advantage nor disadvantage of 3D maps compared to 2D visualizations (D. M. Savage et al., 2004).

A few years earlier, St. John, Smallman, & Cowen (2000) also concluded that 2D topographic visualizations delivered better results for relative positioning tasks. In their study, however, an oblique perspective view of the terrain resulted in better performance for shape understanding tasks. For these tasks, participants were asked to decide whether it is possible to see a point from a given point of origin in the terrain. As a conclusion for topographic representations, St. John et al. (2000) recommended to distinguish between shape understanding and spatial positioning purposes for the choice whether to use a 2D or 3D visualization. For example, St. John et al. (2000) drafted a military concept called “orient and operate”. This concept proposes to use a 3D visualization to initially orient and gain an understanding of the shape of objects or terrain, while a 2D visualization can be used to measure distances or define movement strategies.

Zhu & Chen (2005) adopted the knowledge from previous studies that a 3D interface does not have to be superior in any cases. However, they proposed another approach by using interactive animation (Zhu & Chen, 2005). With an interactive visualization, Zhu & Chen (2005) wanted to avoid the problem of symbol occlusion by allowing the participants to choose their own multiple points of view. They found out that even with an interactive animation, some impairments in form of hidden symbols remained. In the 3D interface, participants may had an additional cognitive effort to find an appropriate display angle (Zhu & Chen, 2005). However, Zhu & Chen (2005) concluded that an interactive 3D visualization still might be a promising approach.

A more recent work by Biljecki et al. (2015) underlines these conclusions. They provided a list of use cases of 3D city models in order to understand and document the current state of their usability (Biljecki et al., 2015). Based on this broad literature list, they confirm that 3D may decrease performance where the visualization’s aim is to read data from a plot (Dall’acqua, Cöltekin, & Noetzli, 2013). However, as we have seen in the previously presented studies, performance seems to be similar in tasks that require elevation information (D. M. Savage et al., 2004). For tasks such as shape understanding, 3D appears to be more accurate (Mark St. John et al., 2000). In summary, the state of research in measuring the usefulness of 2D vs. 3D visualizations is rather inconclusive (Niedomysl et al., 2013).

2.4.2 User’s preferences

In chapter 2.4.1, some important findings regarding comparative studies between 2D and 3D visualizations were presented. This chapter also focuses on empirical studies on this topic, but instead of the performance, it concentrates more on the preferences of the users.

The broad literature list compiled by Biljecki et al. (2015) revealed that in most cases users appear to prefer 3D over 2D. Biljecki et al. (2015) uses the term naïve cartography, since 3D has not proven to be the better solution. However, it seems that many non-expert map users have difficulties reading 2D topographic maps or do simply prefer 3D visualizations to avoid the interpretation of contour lines, shaded reliefs and height points (Schobesberger & Patterson, 2008). In their study, Schobesberger & Patterson (2008) asked 185 hikers with a questionnaire whether they prefer 2D or 3D maps. Figure 16 shows the 2D and 3D maps used for their study.

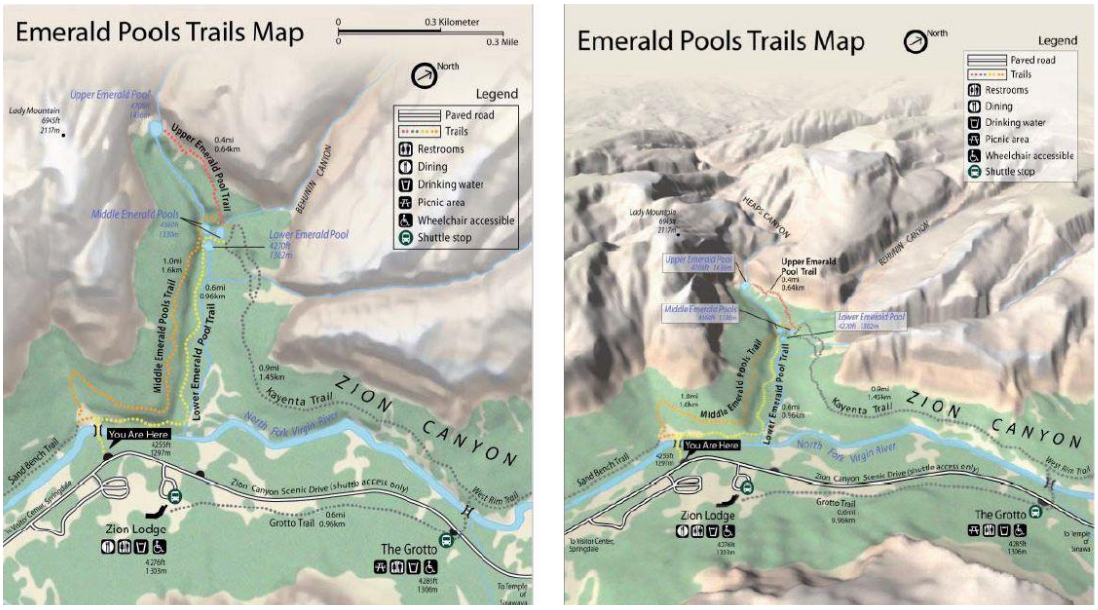

Figure 16: 2D (left) and 3D (right) hiking map (Schobesberger & Patterson, 2008)

This questionnaire did not reveal a clear preference. 48% preferred the 3D map, while 47% favored the 2D map (Schobesberger & Patterson, 2008). Nevertheless, the study showed a significant relation based on demographic characteristics. For instance, 3D maps were clearer preferred by the 26-40 age group, whereas the other age groups (15-25, 41-60 and 60+) tend toward the 2D maps (Schobesberger & Patterson, 2008). In a related study, 2D and 3D landslide vulnerability maps of Batu City, Indonesia were visualized and evaluated based on user preferences (Wahyudi, Ramdani, & Bachtiar, 2020). Interviews with 10 participants revealed that 90% preferred 3D visualization over the 2D visualization. Figure 17 shows the 2D and 3D visualizations used for their study.

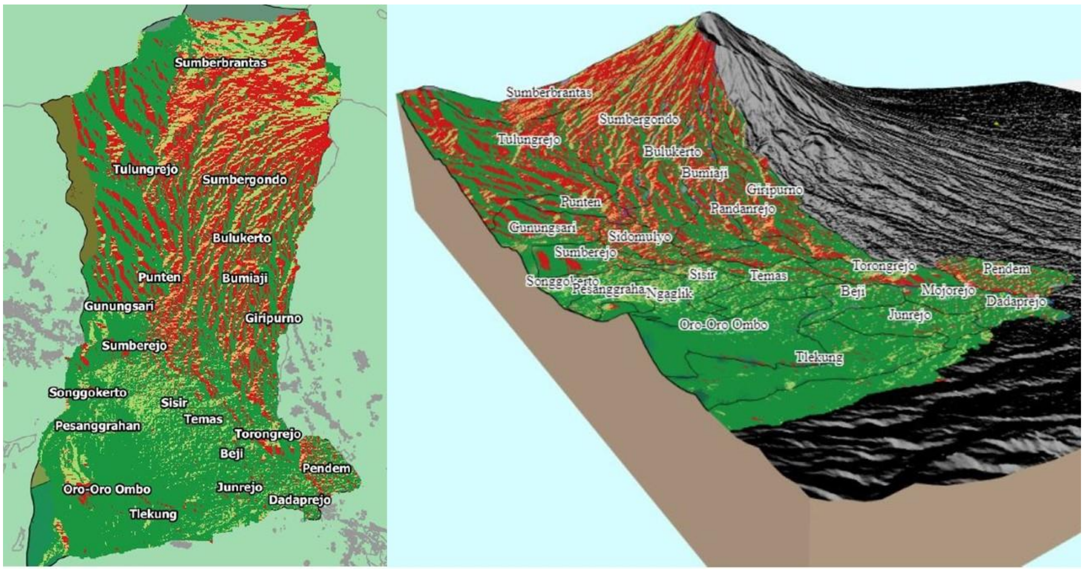

Figure 17: 2D (left) and 3D (right) visualizations (the darker the more vulnerable) (Wahyudi et al., 2020)

Interviews have the advantage over the questionnaires in that the researcher is able to gather information about the reason for participants' preferences. On the one hand, they argued that 3D generally looks better and on the other hand, participants indicated that they can see the slope more clearly in the 3D visualization (Wahyudi et al., 2020).

Popelka & Brychtova (2013) also identified the issue that non-expert map users have difficulties reading 2D topographic maps. In their study about different perceptions of 2D and 3D terrain visualizations, a questionnaire showed in a first step that a majority of participants also prefer 3D visualization. In contrast to many other studies, Popelka & Brychtova (2013) used eye-tracking technology in a second step. The aim was to investigate differences between cognitional efforts of 2D maps and their equivalents presented as 3D visualizations. They found no significant differences in most eye-tracking metrics. Some differences occurred only in scan path length (Popelka & Brychtova, 2013). A longer scan path is a sign for less efficient searching. Somewhat surprising, participants with a background in cartography had longer scan paths than non-cartographers in all cases (Popelka & Brychtova, 2013). Referring to the recommended division of 2D and 3D visualizations into distance and shape understanding tasks from the previous chapter 2.4.1, this study also showed a distinction of user preferences between these types of tasks. In 10 out of 11 cases, a majority of participants indicated that 3D visualization was better suited for finding a right answer. Only for the task where participants had to compare the distances between points, they found the 2D visualization more suitable (Popelka & Brychtova, 2013).

Petrovič & Mašera (2007) investigated users' preferred map for four different tasks (measurement of distance, measurement of height difference, defining North direction and impression about the route) and the question whether one would consult the 2D or 3D map to find the answer. On the one hand, a majority of users stated to use 2D maps for tasks involving the gathering of numerical data such as measuring distances. On the other hand, 3D visualizations seem to be favored to get an adequate impression of a route between two points (Petrovič & Mašera, 2007).

2.4.3 Focus on flood risk visualizations

After having presented the results regarding general comparative studies between 2D and 3D visualization and concerning user preferences in the previous two subchapters, I want to transfer these findings to the field of flood risk communication.

In 2D flood maps, the impacts of flood hazards can only be viewed from an orthogonal perspective. In 3D visualizations, the user can also view the impact from an oblique perspective. Leskens et al. (2017) pointed out that flood depths could even be estimated without the consultation of a legend in which mostly different shadings or colors are used to indicate the flood depth.

Leskens et al. (2017) discovered that 3D visualizations have an added value for users of flood maps compared to 2D visualizations. The authors conducted a user study with the open question what the added value of the 3D visualization actually is. Among others, the following statements of users regarding 3D visualizations were collected (Leskens et al., 2017):

- "It makes it better possible to imagine the consequences of the flood"

- “It enhances prediction of what a flood means for an area and helps to better emphasize with the situation”
- “It is more realistic and detailed. It is easier to interpret what a flood means for the area”
- “It is more vivid and therefore better understandable”
- “Less interpretation is required to estimate the consequences of the flood”
- “It helps the user to better imagine how serious the flood is”
- “It shows the consequences for the environment better”

In this study, most participants indicated that the 3D visualization contributes to a better understanding of the consequences in terms of damages, loss of life and potential evacuation (Leskens et al., 2017). Participants stated that in the 2D visualization, they first had to translate the different blues into flood depths and only then they were able to estimate the impact of the flood (Leskens et al., 2017).

With regard to the flood risk communication, many researchers agreed that using 3D flood visualizations can improve the understanding of a hazard and risk especially for a non-expert audience (Biljecki et al., 2015; Evans et al., 2014; Macchione et al., 2019; Zhi et al., 2020). Rollason et al. (2018) emphasized that current flood risk communications “are having limited impact on driving risk awareness or resilient behaviours”. Macchione et al. (2019) recognized this lack of risk awareness in the public due to the following facts: Firstly, current flood hazard maps do not have a good balance between simplicity/complexity and readability/usability for the public. Secondly, it is challenging for a non-expert audience to understand probabilistic hazard information. Thirdly, the majority of the public has no direct experience with flooding, which makes the imagination of a flood difficult (Macchione et al., 2019). Evans et al. (2014) also wrote in their paper that an effective flood risk communication is especially challenging for communities that have rarely experienced flooding. According to the authors, this lack of direct experience has the greatest impact on ignorance of a potential future flood event (Evans et al., 2014). In their study, Evans et al. (2014) created 3D visualizations (see the example in chapter 2.3.3) to raise awareness in the public of Exeter, UK. In October 1960, Exeter experienced a devastating flooding that flooded many properties to a depth of almost two meters (Evans et al., 2014). However, the majority of the population cannot remember the flood and is not aware of any future threat of flooding. Macchione et al. (2019) addressed this problem and in their opinion, 3D visualizations can serve as pictures, which replace missing historical photos and explain the consequences of a flood event (Macchione et al., 2019). In Exeter, the presentation of the 3D visualizations led to some changes in public perceptions of flood risk. In addition, this visualization gave also rise to a debate in the local government about the current flood policy (Evans et al., 2014). In summary, Leskens et al. (2017) showed that people are more sensitized to flood risk through 3D visualization rather than through classical 2D flood maps. Thus, risk communication influences our perception (Macchione et al., 2019). People seem to be more aware of flood risk with 3D visualizations, as 3D visualizations provide more valuable information for the flood risk management (Zhi et al., 2020). For example, Macchione et al. (2019) identified the interaction between the flood level and the public-private infrastructure as an additional valuable piece of information, as it is better imaginable than with 2D visualizations.

2.5 Flood risk perception

So far, this work has focused on visualizations within the topic of flood risk communication. This chapter is intended to explain in more detail the human being's cognitive processes in the interpretation of these flood visualizations. This important factor in flood risk communication is the process of risk perception. Many contributions to the current understanding of risk perception were made within the research fields of geography, sociology, political science, anthropology and psychology. Lechowska (2018) stated that the research about perception of risk is mainly a domain of sociological sciences. However, the context of risk perception in the face of natural hazards has been mainly studied by geographers (Slovic, 1987). In this chapter, the most common definitions of risk perception and their systematizations proposed in the scientific literature are examined. Furthermore, the most influential factors on our perception of risk are presented.

2.5.1 Definitions and systematizations

In the literature, risk is considered a quantifiable phenomenon. In most cases, it is the result of the analysis of probabilities and their consequences (Raaijmakers, Krywkow, & van der Veen, 2008). Meanwhile there are various definitions for risk perception. According to Slovic (1987), risk perception can be considered as intuitive risk judgements by humans. Also Bradford et al. (2012) rely on this definition and understand risk perception as "an individual's interpretation or impression based on an understanding of a particular threat that may potentially cause loss of life or property". In the definition of Wachinger, Renn, Begg, & Kuhlicke (2013), the authors focus more on the naming of a process in which signals about uncertain impacts of events are collected, selected and interpreted. Lechowska (2018), however, interpret the term more in the context of the definition of risk. In her opinion, risk perception is the result of the hazard probability and its consequences perceived by society. As can be recognized, there are many definitions of risk perception with the similar understanding of risk but a slightly different focus how perception should be determined. In this thesis, perception is considered as the individual process of understanding a situation as described by Raaijmakers et al. (2008).

Since risk perception is an individual process, perceptions may differ due to several factors. Some people might interpret a situation as not risky, while others consider the same situation as risky. Thus, it is essential to determine a systematization of the term risk perception based on the different factors and how risk perception is influenced by these factors. This understanding is crucial for determining the suitability of flood risk communication in terms of increasing trust and resilience (Bradford et al., 2012). In the paper of Bradford et al. (2012), the factors influencing public's risk perception are divided into situational and cognitive factors. In relation to the topic of flood risk, situational factors describe the individual's physical location to a flood prone area. Thus, the main factors are the characteristics of the hazard, previous flood experience and demographic profiles (age, gender, education level, profession etc.). For instance, the judgement of risk may differ between the public and experts (Raaijmakers et al., 2008). Cognitive factors are more related to the individual's personal and psychological interaction that leads to actions in some ways. Regarding flood risk, the emotions aroused by the flood, including individual's affective and behavioral characteristics, provide insights into tendencies how people perceive and react (Bradford et al., 2012). For instance, some people might have an increased fear of being flooded due to previous experiences, while other people perceive a situation in the meantime as less risky. In this context, personal interpretation of previous experiences, emotions and feelings as well as the demographic profile seems to result in a measure of Slovic's (1987) described "intuitive risk judgements".

Another systematization of flood risk perception is presented by Raaijmakers et al. (2008) with its characteristics awareness, worry and preparedness. With help of this systematization, the understanding of individual's perception of risk shall be facilitated and thus, enable a more efficient flood risk communication. Figure 18 shows the relationship between these flood risk characteristics.

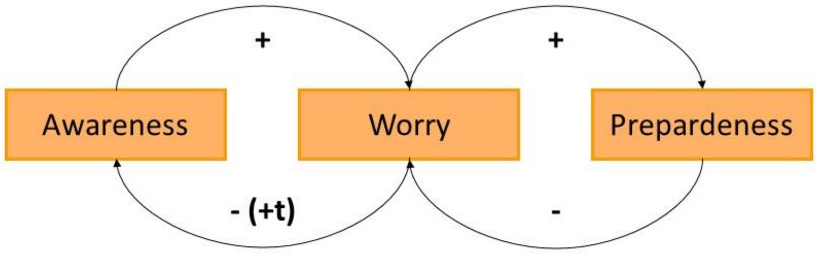

Figure 18: Flood risk characteristics and their relationship, t = time period (based on Raaijmakers et al., 2008)

Awareness of flood risk describes the individual's knowledge about the flood risk he or she is exposed to. Worry depends on the expected severity of a flood, which in turn depends on the flood risk awareness. Thus, individuals might worry more or less about the consequences of flooding. Preparedness can be considered as the capability of getting along with a flood in case of occurrence and as the capability of recovery (Raaijmakers et al., 2008). Raaijmakers et al. (2008) defined risk perception as the relationship between these flood risk characteristics. Firstly, flood risk awareness of an individual increases under the following conditions: (1) confrontation with a hazard and (2) widely available information and education about the hazard (Raaijmakers et al., 2008). Secondly, a society with an increased flood risk awareness is a society with a higher level of worry. This higher level of worry leads to a better preparedness for floods. However, a better prepared society will be less worried. Long periods without floods (+t) with reduced worry probably lead to a decline in awareness (Raaijmakers et al., 2008). For example, an earthquake and tsunami killed 3,000 people in Fukushima in 1933. After a while, people started to associate tsunamis as minor events since the warnings resulted in only little damages (Wachinger et al., 2013). Not surprisingly, the disaster in 2011 was first ignored although early and urgent warnings were triggered (Wachinger et al., 2013).

This systematization of flood risk should help to understand the public's risk perception and this understanding leads to more effective risk communication by constituting awareness among the public (Raaijmakers et al., 2008). However, Bradford et al. (2012) investigated in their paper the contribution of this systemization of Raaijmakers et al. (2008) to the risk perception theories, since the presented interrelationships are controversially discussed in research. The following chapter 2.5.2 will deal with these controversial discussions.

2.5.2 Controversial discussion in risk perception research

On the left side, Figure 19 shows the result of an empirical study by Bradford et al. (2012) on the relationships of the risk characteristics, while the right side shows the findings of the literature review from Lechowska (2018).

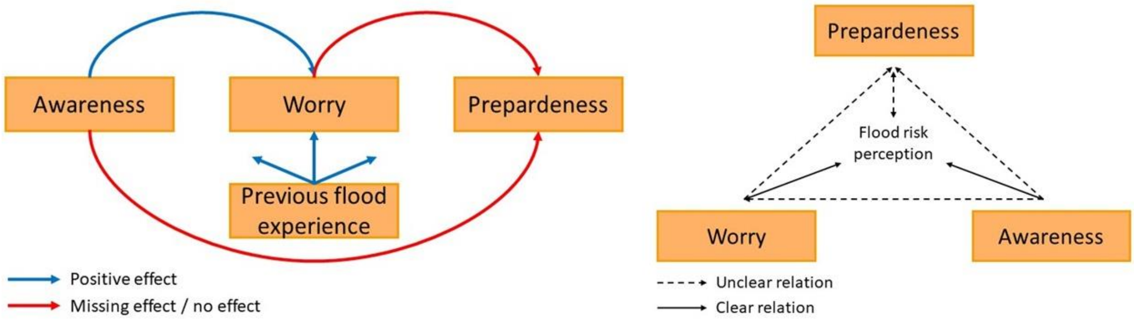

Figure 19: Relationships of the risk characteristics according to Bradford et al., 2012 (left) and Lechowska, 2018 (right)

In their quantitative research with 1375 questionnaire responses from six European countries, Bradford et al. (2012) found no correlation between awareness / worry and level of preparedness. As a result, worry does not seem to be the linking characteristic between awareness and preparedness (Bradford et al., 2012). Although there was found no correlation between risk awareness and preparedness level, a direct influence of previous flood experiences and level of preparedness could be identified (Bradford et al., 2012). Thus, it seems that people who experienced a flood in the past show a better preparedness than people without any experienced floods. However, the opposite effect is found in the literature as well. Wachinger et al. (2013) mentioned that individuals who experienced a hazard event with no personal damages are more likely to show decreased preparedness for a future event. This can be seen as an example for the complex and contradictory relationships of flood risk characteristics within the concept of risk perception. Although Bradford et al. (2012) found a relationship between awareness and worry, Lechowska (2018) defined it as an unclear relation. Despite this, Lechowska (2018) described the relationship between awareness / worry and flood risk perception as unequivocal. Similarly to Bradford et al. (2012), the relation between preparedness and awareness/worry is unclear in Lechowska's (2018) flood risk perception research.

Another factor influencing the flood risk perception is the distance or proximity to a hazard (O’Neill, Brereton, Shahumyan, & Clinch, 2016). Lechowska (2018) has shown that awareness and worry are unequivocal determinants for flood risk perception. However, only a small number of researchers investigated the influence of proximity to a hazard zone on risk perception. They mainly concluded that people living close to a hazard zone are often more concerned, while this emotion tends to decline with distance (O’Neill et al., 2016). In their paper, O’Neill et al. (2016) focused especially on the distance to the perceived flood zone with the use of cognitive maps. Each participant in their study generated a cognitive map of flood prone areas in Bray, Ireland. As a result, no relationship between worry and real distance to a river was found. Nevertheless, a significant relationship between worry and the distance to the perceived flood zone was found. Thus, the distance to the perceived floodplain seem to be an important influencing factor in determining flood risk perception. The smaller the distance to the perceived floodplain, the higher the flood risk perception (O'Neill et al., 2016).

The aim of this chapter was to emphasize that the understanding, how the public views flood hazard and risk, is an important factor in designing flood risk communication (O'Neill et al., 2016). The publication of flood hazard and flood risk maps, as a form of flood risk communication will facilitate further acceptance and awareness of risk by enabling public discussions (Bradford et al., 2012).

2.6 Risk measures

As it will be explained in chapter 3, the participants had to make decisions based on flood risk in the main experiment. Thus, it is important to consider the individual risk attitude as well.

2.6.1 Individual risk attitude

A risk-averse person behaves differently than a risk-seeking person during a task with a risk component. For instance, a risk-averse person chooses the safest win and accepts that the win might be lower. As Figure 20 indicates, the possible loss is weighted more than the possible gain and the value function in general tends to be concave for gains while it is rather convex for losses (Kahneman & Tversky, 1979).

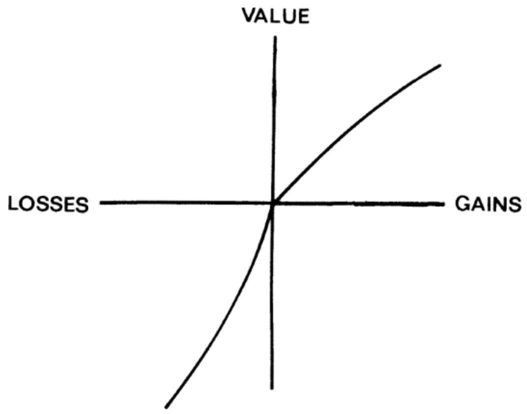

Figure 20: The hypothetical value function of Kahneman & Tversky (1979)

Risk-seeking person weight positive deviation potentials from an expected result higher than negative deviation potentials (Wagner, 2014). Consequently, different risk behaviors seem to influence decisions under risk. In this study, it is important to note that the differences in the risk perception between the 2D and 2.5D visualizations can be attributed to the different dimension rather than to the individual attitudes to the risk. Thus, risk will be measured as a pretest before the actual main experiment in order to evaluate its influence on risk perceptions.

2.6.2 Balloon Analogue Risk Test

Previous works dealing with decisions under risk also mentioned that it is important to measure the risk attitude (Kübler et al., 2019). There are many different measures to consider risk attitudes. Many measures focus on self-report measures. However, self-report measures face the problem of potential limitation of veracity and the possible lack of insight or ability to provide an accurate report of an own behavior (Lejuez et al., 2002). Thus, a risk measurement without the need of self-reporting will be used for this study. In addition to this, it is recommended to use simple tasks to avoid complex interpretation of the results (Kahneman & Tversky, 1979).

To address this issue, the Balloon Analogue Risk Task (BART) designed by Lejuez et al. (2002) was chosen. BART is a risk measure presented on the computer. The measurement involves actual risky behavior. This means that taking risk is rewarded up until a certain point at which taking further risk results in poorer outcomes (Lejuez et al., 2002). Thereby, a small balloon is presented on the computer screen. Participants can inflate the balloon by clicking the "space" key. Each click inflates the balloon a little bit and the participants earn virtual CHF 0.05. This virtual money is collected and summed up in a temporary reserve. When a balloon reaches its maximal inflation point, it will explode and all collected money in the temporary reserve is lost. However, at any point during the inflation phase, participants can click the "enter" key and stop inflating the balloon. Then the collected money from the temporary reserve is transferred to a "safe bank". BART represents an intuitive and simple task as Kahneman & Tversky (1979) suggested. Furthermore, the interpretation is quite straightforward by recording the number of pumps. Lejuez et al. (2002) decided to only consider the adjusted number of pumps as an index of riskiness that is defined as the average number of pumps excluding the exploded balloons.

2.7 Research questions and hypothesis

2.7.1 Integration of the thesis into the research context

Previously, I have explained different approaches to communicate flood risk. Chapter 2.2 gave an overview over various types of flood maps in 2D format. Chapter 2.3 highlighted the role of the third dimension in flood risk communication, while the current state of research regarding the usefulness of 3D compared to 2D was presented in chapter 2.4. These different approaches to flood risk communication were included in the current discussion about their influence on flood risk perception in chapter 2.5. It has been discovered that visualizations, whether 2D or 3D, play an important role in people's risk perception (Lieske et al., 2014).

Flood risk perception became particularly important in research a few years ago. The understanding of people's risk perception and the determination of its influencing factors is considered essential for improving risk communication and raising awareness (Kellens et al., 2011). There are early studies on the concept and systematization of flood risk perception which turned out to be controversial in terms of evaluating the significance of some influencing factors (Bradford et al., 2012; Kellens et al., 2011; Lechowska, 2018; O'Neill et al., 2016; Raaijmakers et al., 2008).

Somewhat surprisingly, the type of visualizations is not widely considered as an influencing factor in literature.

Thanks to technological advances and progresses, new types of visualizations have become available for risk communication. Especially the advantages and disadvantages of 3D flood visualizations compared to their equivalent 2D versions are widely discussed in scientific literature (Evans et al., 2014; Leskens et al., 2017; Macchione et al., 2019; Rollason et al., 2018; Zhi et al., 2020). This discussion focuses mainly on the user preferences and performances. However, there seem to be not many studies that focus on the human perception of 2D and 3D flood visualizations instead of bringing decision performance into focus.

Consequently, a research gap can be identified from both research perspectives. To my knowledge, existing research on flood risk perception has not focused enormously on the type of visualization as an influencing factor and research on comparative studies between 2D and 2.5D visualizations has not primarily considered human risk perception. This thesis aims to fill this research gap by investigating how 2D and 2.5D flood visualizations affect our risk perception.

2.7.2 Research questions and hypothesis

In order to achieve this aim, this research question is divided into the following three research questions:

RQ1) How do people rate their risk perception when viewing a 2D flood visualization compared to a 2.5D flood visualization?

RQ2) What drives possible differences in response time between a 2D and a 2.5D flood visualization?

RQ3) How do people's individual attitudes towards risk affect their risk perception?

The following hypotheses were formulated for these research questions and will be verified or falsified in chapter 4.

Hypothesis on RQ1: From a general point of view, Kraak (2003) stated that the 3D version of Charles Minard map "Napoleons March on Moscow" appears more dramatically. This apparent 3D visual characteristic also seems to be used in the study of Evans et al. (2014), in which a 3D flood visualization was created for Exeter, UK to raise flood risk awareness in the public. The possibility to visualize additional information in a further dimension improves the readability and usability for most people (Macchione et al., 2019). Based on those statements from the literature, 3D visualizations seem to work better than 2D visualizations as a "wake-up call" in terms of increasing risk awareness. Thus, the hypothesis for the first research questions is formulated as follows:

The participants assess the flood risk on a 2D visualization significantly lower than on a 2.5D model.

Hypothesis on RQ2: As mentioned in chapter 2.4, participants of the study of Leskens et al. (2017) quoted among other things: "Less interpretation [in 3D visualizations] is required to estimate the consequences of the flood". In this way, and under the condition that less interpretation leads to a shorter reaction time, the participants seem to need less time to respond. However, Fabrikant et al. (2014) emphasized that cognitive demands can also increase with a third dimension. But since the additional effort seems to be mainly related to the participant's interaction with interactive visualization and since the 3D visualizations in this study are static (see more on that in chapter 3.3.2), this increased cognitive demand is probably minimized. Thus, the hypothesis for the second research questions is formulated as follows:

The participants need significantly more time to make decisions about their risk perception on a 2D visualization than on a 2.5D visualization because of less cognitive efforts in estimating the consequences of the flood.

Hypothesis on RQ3: A potential difference in risk perception between 2D and 2.5D visualization can also be rooted in the different risk attitudes of the participants. It is likely that some participants of the study will behave riskier than others because they are less risk-averse characters. As it will be shown in chapter 3.2.2, a risk-seeking person weights positive deviation potentials from an expected result higher than negative deviation potentials (Wagner, 2014). Thus, the hypothesis for the third research question is formulated as following:

The more risk-seeking a participant is the lower are his or her risk ratings based on the flood visualizations. Thus, the participants' risk attitudes have an influence on their risk perception.

3 Methods

In order to answer the research questions, an experimental study was conducted. In the first part of this chapter, a description of the study structure is introduced. In the second part, I will explain in more detail the materials and procedures of the experiment. Finally, the participants are presented and the performed data analysis is described.

3.1 Study structure

The study is divided into three parts: a pretest, the main study and a posttest. A detailed description of the individual parts of the study follows in the next chapters. However, this chapter provides a general overview of the structure of the study. First of all, the pretest had to be done. As a first part of the pretest, the participants had to fill out a personal questionnaire that gathered information about their demographic background and their prior knowledge in areas such as cartography, flood maps etc. A further element of the pretest was the BART to measure participants' individual attitudes towards risk (Lejuez et al. 2002). Secondly, the main experiment followed in which the participants were split up into two groups. In this second part, the participants in the 2D group were asked to rate their risk perception for building a house by using 2D flood visualizations, while the participants in the 2.5D group were asked to do the same using 2.5D flood visualizations. In the third and last part, the participants were encouraged to repeat a small fraction of the tasks from the main experiment. However, this time to think aloud while solving the tasks. The following Figure 21 provides an overview of the structure of the study:

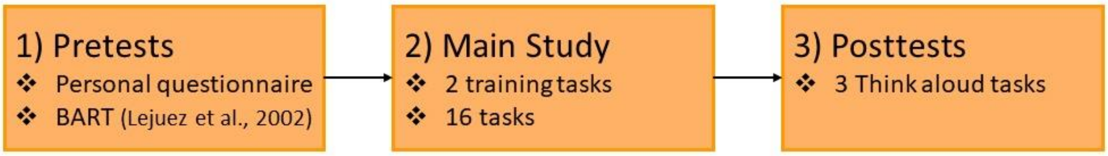

Figure 21: General structure of the study

The study was conducted in the time between 22 October 2020 and 19 November 2020. The study duration per participant was approximately 20-30 minutes and was mainly conducted in the area of Lucerne. Due to COVID-19 and the more stringent measures (recommendation for home-office, mask obligation etc.) imposed by the Swiss government, I did not want to encourage all the participants to travel to the study place. Thus, I decided to visit participants (preferably by car) so that they could conduct the study on my personal laptop. Consequently, not all participants had the same room condition. However, it could be guaranteed that every participant solved the study on the same laptop with the same hardware and desktop resolution and, most importantly, with no disruptions (see more in chapter 3.3.1). The computer is an ASUS ZenBook UX430UN-GV060T and the screen has a size of 14'' and a resolution of 1920 x 1080 pixels.

Also due to the special situation of COVID-19, I developed and implemented the following hygiene protocol for each participant and study:

Before the study:

- Hand disinfection
- Cleaning of keyboard and mouse with disinfectant
- Disinfection of the pen with which the participants sign the consent form

During the study:

- Keeping at least 1.5m distance
- Supervisor and participant wear a mask

After the study:

- Hand disinfection
- Cleaning of keyboard and mouse with disinfectant
- Disinfection of chair and table

I was physically present throughout the study, but emphasized that I was not looking at the desktop while the participants solved the tasks in order to avoid different behaviors due to the feeling of being observed.

3.2 Pretest

Before the main experiment with the 2D and 2.5D visualizations respectively was conducted, the participants had to fill out a personal questionnaire and solve a risk attitude test. The personal questionnaire was answered by the participants with an online survey (www.findmind.ch) on their own electronic device whereas the risk attitude test was solved afterwards on my personal computer.

3.2.1 Personal questionnaire

The aim of the personal information questionnaire was to receive a general impression of the participants. In a first part, the participants were asked about their age and gender. Secondly, the participants had to indicate whether they had a diagnosed red-green visual impairment or color blindness. Thirdly, the participants were asked about their education and how often they use maps in their leisure time. Finally, they were also asked about their experience with cartography, geographic information systems, digital maps and flood maps. The ID-number of the participant was filled out by me and ensures the data merging between questionnaire and main experiment. The complete personal questionnaire can be viewed in the appendix C.

3.2.2 BART

In their paper, Lejuez et al. (2002) proposed 90 balloons with three different colors (each color has a different probability to explode). However, the time expenditure for the participants for the whole experiment should not be too big. Thus, in the pretest of this study, only 20 balloons of the same color were presented to the participants on the computer screen. This decision was also supported by the fact that Lejuez et al. (2002) analyzed the riskiness in their paper by only using the number of adjusted pumps on one color. In the BART for this study, each balloon had the same color but a different defined maximal number of pumps. The number of pumps represents a balloon size which ranges from extremely small to almost as big as the whole computer screen.

3.2.3 Procedure of the Pretest

The participants sat down at a desk where he or she found the consent form (see Appendix B). After a brief oral explanation about the study's content and structure, participants signed the consent form. Then, he or she was asked to fill out the personal questionnaire.

The link to the questionnaire was sent by WhatsApp right after they signed the consent form. Thus, the participants completed the personal questionnaire on their own smartphones. Afterwards, the participants were asked to focus on the laptop screen where they received the instructions about the BART. After confirming that they had understood the instructions, they were able to carry it out without interruption. The participants solved 20 balloon tasks. They had no time restrictions and they did not know that their risk behavior was measured. Both the BART pretest as well as the main study described in chapter 3.3 were performed by the participants with the software PsychoPy (see more on the implementation of the study in PsychoPy in chapter 3.5).

3.3 Main experiment

The aim of this thesis is to investigate whether the change in dimensionality of flood visualizations has an influence on our risk perception. In order to answer this question, 2D and 2.5D flood visualizations were presented to participants. Both 2D and 2.5D flood visualizations display the same area. In each flood visualization, a house icon symbolizes the location where a participant could hypothetically build a house. As Kübler (2016) mentioned in her master thesis, it is quite important to consider natural disasters when buying or building houses in densely populated Switzerland where many people live in areas exposed to natural hazards. Due to this reason, this study focuses on a house site evaluation where participants have to rate their perception of how risky it is to build a house on a specific site. They only had flood visualizations as a basis for decisions. Further information such as house prices, description of the location etc. was not given. Consequently, participants could mainly focus on the information given by the flood visualization.

In the following subchapters, I will describe and discuss the study design (3.3.1) of the main experiment, some decisions regarding the design of the flood visualizations (3.3.2), data and software for the creation of the flood visualizations (3.3.3), the workflow of flood visualizations generation (3.3.4) and the procedure of the main experiment with participants (3.3.5).

3.3.1 Study design

The type of flood visualizations, namely 2D and 2.5D visualizations, represents the independent variable. An independent variable is defined as an element that is manipulated during the experiment (Martin, 2008). Basically, the variable is independent of the participant's behavior and this study wants to investigate a potential change in behavior due to the independent variable (Martin, 2008).

The behavior I would like to measure is called dependent variable (Martin, 2008). In this study, I want to investigate whether a change in dimensionality of flood visualization leads to different perceptions of risk and different response times. Thus, the two dependent variables are risk perception and response time.

An experimental study wants to measure the dependent variable by changing the independent variable. However, the independent variable is most of the time not the only thing that changes during the study. Thus, it is important to minimize or at least control all the other changing circumstances (Martin, 2008). Those changing circumstances are called control variables (Martin, 2008). If an experimenter knew that all variables except the independent variable remained constant, then he or she could be sure that any change in the dependent variable has its reason in the independent variable (Martin, 2008). In this study, every participant used the same laptop and solved the tasks with the same mouse. The use of same hardware ensures that no result is influenced because of different conditions. For example, a participant who solves the tasks with the mouse is probably faster than the participant with the touchpad. However, due to external validity, it is sometimes recommended to not control all the variables (Martin, 2008). In chapter 3.1, I argued that because of the COVID-19 situation the recruitment of participants was more efficient if I abandoned the control variable "room condition", which would ensure that each participant was in the same room with the same light condition. An additional advantage of this decision is also manifested in the minimization of suffering from threats to external validity (Martin, 2008). In practice, it is very unlikely that the public will consult flood visualizations with the same room conditions.

The study uses a between-subject design, meaning that not all participants were assigned to the same independent variable (Martin, 2008). One of the main advantage of a between-subjects design is that the exposure to one independent variable (e.g. 2D visualization) will not contaminate the behavior of the participants under the other independent variable (e.g. 2.5D visualization) (Martin, 2008). If the study design allowed participants to see both independent variables, participants could learn to process the information better as the study progresses. As a consequence, it is possible that they would make faster decisions the more the study is approaching its end and this would distort the study. As a second advantage, a between-subject design enables a shorter total experimental time as the participants are only exposed to one independent variable (Martin, 2008). However, it is also essential to be aware of the between-subject design's disadvantages. Probably the biggest disadvantage is that the different groups of participants might not be equivalent to each other and this could bias the collected data (Martin, 2008). In order to mitigate this disadvantage, Martin (2008) recommends randomizing the process of assigning participants to a group. Especially for big sample sizes, it is rather unlikely that the groups are quite different from each other (Martin, 2008). Nevertheless, I decided not to use a randomization process to assign participants to one of the two groups since the group size is not as big as in a long-term study and the probability that the two groups are different from each other is, therefore, higher. To ensure that the two groups do not differ too much, participants were assigned to a group based on their age and gender. Furthermore, the existing literature agrees that age and gender play a significant influence in risk perception (Kellens et al., 2011; Lieske et al., 2014). Therefore, the division by age and gender is also a preventive measure, so that the result is not influenced due to these two demographic characteristics. Figure 22 shows the design of the main study.

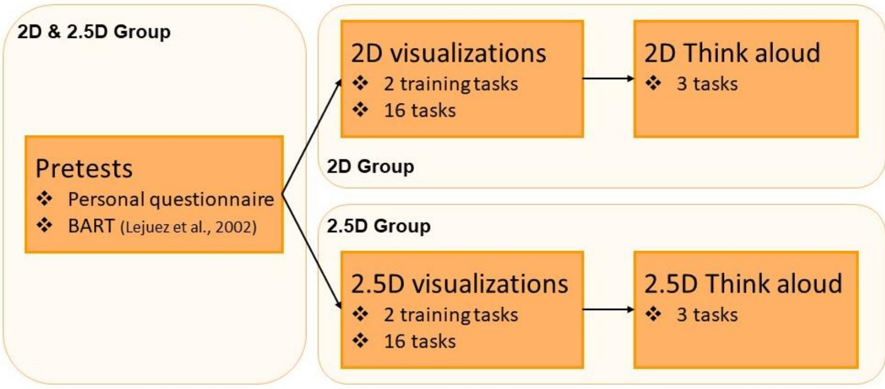

Figure 22: Design of the study

During the main study, participants solve 16 tasks with the help of flood visualizations. Participants assigned to the 2D group will see 16 2D visualizations and participants assigned to the 2.5D group will see 16 2.5D visualizations. In the beginning of the main study, the overall aim of the study to investigate potential differences in risk perception between 2D and 2.5D visualizations was not told to the participants. Consequently, the participants did not know that another type of visualizations existed. The order of the 16 visualizations is randomized for every participant. This procedure ensures that a possible learning effect will not influence the results of single visualizations as the study progresses. A more detailed description of the main experiment's procedure is provided in chapter 3.3.5.

3.3.2 Stimuli: Decisions based on literature

This chapter discusses and explains some important decisions that were made before the creation of the independent variable, the flood visualizations, was started.

2.5D vs. 3D

On the one hand, 3D has the advantage to visualize man-made features such as buildings and transportation infrastructures sufficiently because 3D is able to deal with vertical surfaces and underground features (Costamagna, 2014). On the other hand, Liang et al. (2016) point out the following technical challenge when dealing with 3D representations: 3D representations are often used in a web context. Web-based 3D GIS faces the challenge of (1) internet data transfer limits and (2) hardware and software compatibility. According to their article, a 2.5D map is an "efficient approach to exploiting a massive 3D city model in web GIS" (Liang et al., 2016). Their paper shows that 2.5D maps can potentially improve the user experience in a web-based context by shortening the time required for data retrieval and rendering. They concluded that "with 2.5D cartography, existing massive 3D city models can be used by a wider audience and in a wider variety of contexts" (Liang et al., 2016).

Flood risk maps, or hazard maps in general, are mostly provided as web-based 2D visualizations (e.g. Geoportal Kanton Luzern, FEMA flood map service center). Flood risk maps cover large areas and it is important that they can be widely used by the public. Based on the argumentation above, the public requires high internet data transfer limits and appropriate hardware and software for a web-based 3D GIS. However, 2.5D maps represent an efficient alternative way to provide a third dimension and improve the user experience compared to 3D GIS. Thus, a 2.5D map seems to be more likely to be implemented in practice than a massive 3D map. Therefore, 2.5D visualizations are used instead of 3D visualizations for this study.

Color map design

Seipel & Lim (2017) pointed out that beside the choice of a suitable type of visualization, the application of an efficient color map is crucial to avoid errors in data interpretation. Seipel & Lim (2017) conducted informal interviews and found out that blue is the associated color for a representation of a flooded area. Thus, I focus on different shades of blues to visualize flood risk.

Continuous vs. discrete representation

For a continuous data type a continuous representation is a good choice (Padilla et al., 2017). Thus, it would be appropriate to visualize flood depths continuously. But in practice, there are a lot of domains (e.g. meteorology) that visualize continuous data with a discrete representation (Padilla et al., 2017). Padilla et al. (2017) further mentioned that it could be beneficial in many situations to represent a continuous phenomenon as a discrete representation. But what is the appropriate choice for which situation? In order to answer this question, it is necessary to understand how our data interpretation is affected whether we use a continuous or discrete representation. Padilla et al. (2017) conducted a study which showed that participants who saw continuous encodings appeared to complete tasks quicker, but the accuracy in performance was superior when using a discrete classification in some of the tasks. Thus, one can argue that accuracy is more important than a fast response time in estimating flood risk. Of course, the task of evaluating a safe location for building a house and the tasks in Padilla et al. (2017) article ("find the highest point" etc.) are quite different. But taking the conclusion of Padilla et al. (2017) into account that discrete representations lead to more accurate decisions, a discrete classification seems appropriate for a flood risk map design. Based on these findings, the flood depth will be visualized with discrete classes for this study.

Static vs. interactive 3D visualizations

The benefits and pitfalls of static vs. interactive 3D visualizations are controversial (see chapter 2.3.2 for more details). To some extent, some pitfalls can be solved with the use of interactive functions such as zooming, rotating, panning etc. In addition, interactive functions are also helpful to understand shapes of 3D-objects instead of seeing them from a static view (Froese, Tory, Evans, & Shrikhande, 2013). Thus, interactive 3D visualizations are considered as richer in terms of information load (Herman & Stachoň, 2016). Nevertheless, Herman & Stachoň (2016) emphasized that several studies about 3D visualizations were conducted with the help of static perspective views as stimuli instead of using interactive stimuli. Herman & Stachoň (2016) investigated differences in user performances with static stimuli and interactive stimuli. They found that the richer amount of information results also in more cognitive efforts for users and in a higher error rate. As a conclusion, participants delivered better results in various tasks with the static 3D visualizations and thus, the interactive 3D visualizations are more useful for experts with previous digital cartographic experience (Herman & Stachoň, 2016).

As not all participants will have the same level of geo-browsing experience, static 2.5D visualizations will provide more experimental control. This means that potential differences in risk perception and response time is not caused by different skill levels in geo-browsing. The static visualizations are based on the map layout template from Spachinger et al. (2008) in chapter 2.2.3.

3.3.3 Stimuli: Study area, data and software

In order to investigate possible differences in risk perception between 2D and 2.5D flood hazard visualizations, flood visualizations of Virginia Beach (USA) were created. In addition to the description of the study area and the data, this chapter also presents the software which was used for creating the independent variable, the visualizations.

Study area

Virginia Beach is an independent city located on the southeastern coast of the state Virginia in the United States of America. The Guinness Book of Records listed Virginia Beach for having the world's longest pleasure beach (VirginiaBeach.com, 2020). However, this water-rich landscape is not only frequently discussed for attracting numerous tourists but also because of the endangerment of the city by possible floods (Hall, 2020). As visualized in Figure 23, the Atlantic can push water from the east, the Currituck Sound from the south, the Elizabeth River from the west and the Chesapeake Bay from the north into the settlement areas. Especially after Hurricane Matthew in 2016, the city has started to focus on how to protect the entire city more from flooding.

Figure 23: Situation plan City of Virginia Beach, USA

Data

Flood data play an important role in order to answer the question of how to protect an entire city from flooding. With appropriate data, one can estimate the expected water level rise during a flood event. In the United States, FEMA is the official source for various flood risk products such as flood risk databases, flood risk maps and flood risk reports (FEMA, n.d.)

The flood risk report provides the results of a community’s study about the flood risk situation. FEMA’s flood risk map is a color-coded map that illustrates the flood risk for specific geographic areas. In this way, it identifies infrastructure that is exposed to a risk within a community. The flood risk database contains datasets in geographic information system formats (FEMA, n.d.). A flood risk database for Virginia Beach, published in the year 2016, is available on the FEMA platform. One dataset within this database is a flood depth grid that delivers information about flood depths in a digital raster format (FEMA, 2020).

According to FEMA’s guidance for flood risk analysis and mapping, the provision of detailed information on flood depth in the form of digital raster datasets is one of the primary ways to communicate flood risk (FEMA, 2018). A digital raster dataset defines a geographic space as a collection of equally sized square cells. The cells are organized in rows and columns and equipped with a value. Figure 24 shows one way to visualize flood risk with a digital raster dataset, where the different shades of blue represent different flood depths (FEMA, 2018).

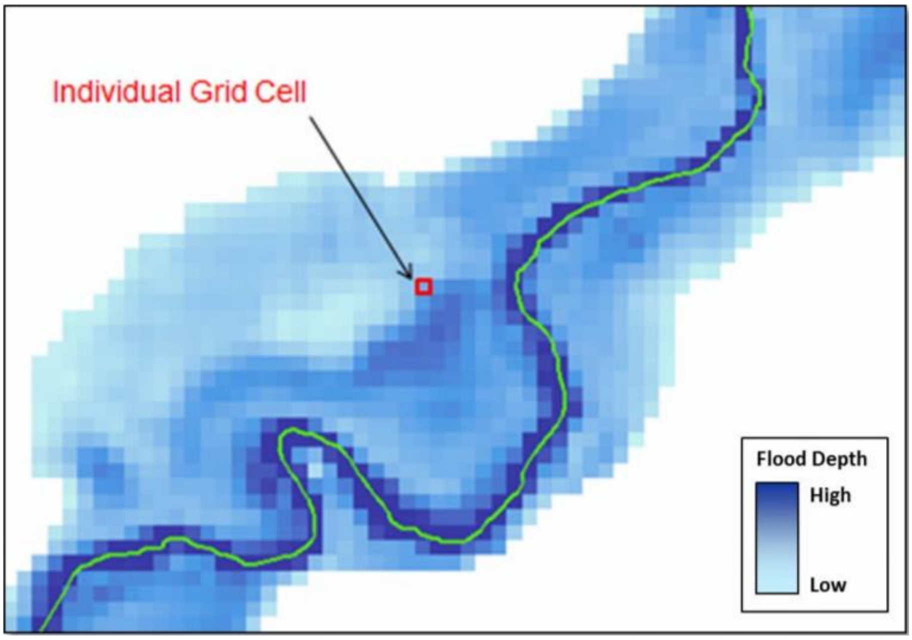

Figure 24: Flood depths visualized with raster data (FEMA, 2018)

ESRI's Flood Impact Analysis solution

Based on the data of the flood risk database for Virginia Beach, flood depth visualizations were created using a solution tool for flood impact analysis. The Environmental Systems Research Institute (ESRI) released the Flood Impact Analysis solution in 2020 (ESRI, 2020a). It represents a tool that guides mapping technicians through the process of creating visual appealing 2D and 3D flood risk analyses. Before the workflow for creating visualizations is explained in more detail, a brief introduction to ESRI's Flood Impact Analysis solution tool is provided.

ESRI designed the Flood Impact Analysis solution tool as a configuration of ArcGIS Pro that can be used to visualize the impact of flooding and to develop flood scenarios (ESRI, 2020b). This configuration contains an ArcGIS project, step-by-step tasks and geoprocessing tools.

In order to develop flood scenarios and visualize the flood impact in 2D and 2.5D, some data and software requirements have to be met. The Flood Impact Analysis solution tool does not do any modelling. It is based on flood models from other sources (e.g. FEMA, NOAA, flood model consultants etc.) and according to ESRI, three types of input data are at least required for the template (ESRI, 2019):

1) Flood depth raster (as shown in Figure 24)
2) Digital Elevation Model (DEM)
3) Features describing the objects to be analyzed (e.g. houses)

Regarding software requirements, ArcGIS Pro 2.3 – 2.5 (advanced edition) is needed as well as the ArcGIS Spatial Analyst and 3D Analyst extension.

ESRI's Flood Impact Analysis solution offers the following benefits (Maren, 2019):

- It defines flood impact areas at each flood stage

- It is possible to determine which infrastructure will be impacted and by how much
- The creation of compelling visualizations makes it easier to understand and communicate the real impact of flooding events

The Flood Impact Analysis solution was evaluated as promising for the study for the following reasons: Firstly, the solution allows answering questions concerning the definition of floodplains and the determination of the flood impact. In practice, both factors have to be considered in order to decide on a building permission (AWEL, 2011; Kanton Aargau, 2018). Consequently, a proximity to practical implementation is given. Secondly, the solution provides flood depth information and offers the possibility to visualize this information in 2D and 2.5D (ESRI, 2020b).

Despite all this advantages, it is also essential to be aware of a limitation of this solution. Since it does not do any flood modelling, the accuracy of the solution is determined by the input data quality. Thus, it is important to have associated meta data describing the data in order to know exactly what the visualizations shows and to narrow down the possibilities and limitations. The description of the meta data for the used flood depth raster can be seen in appendix A.

3.3.4 Stimuli: Workflow for the creation of the visualizations

In this section, a stepwise explanation of the workflow to create the visualizations is presented. The visualizations were designed in ArcGIS Pro 2.3.0. The geographic coordinate system for the ArcGIS project was set to GCS North American 1983, the projected coordinate system to NAD 1983 StatePlane Virginia South FIPS 4502 Feet and the vertical coordinate system to NAVD88 (height) US ft. Figure 25 illustrates the workflow graphically. Based on this graphic, the various workflows for each basic data input (left side of the figure) up to the layers (right side of the figure) are explained.

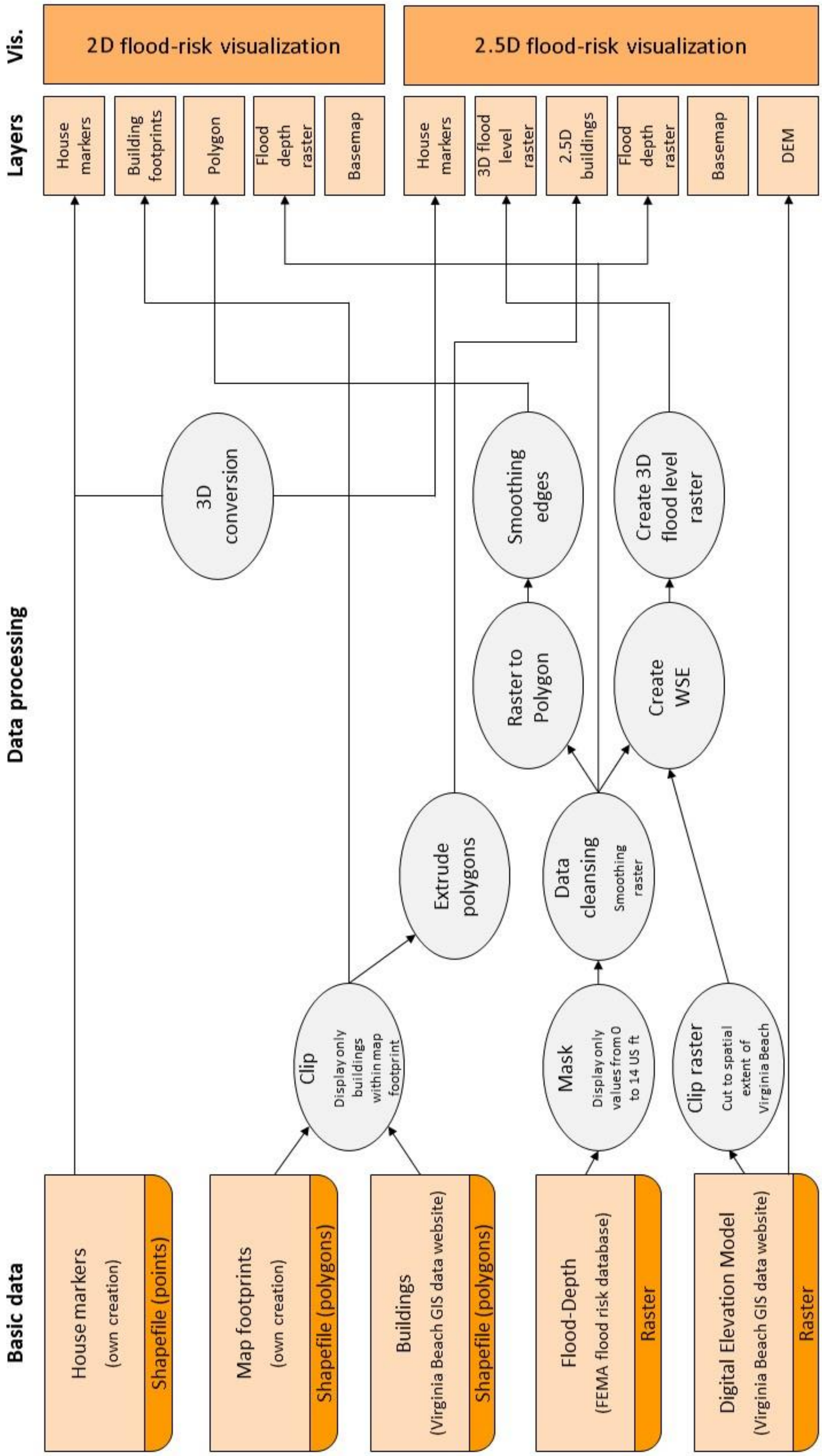

Figure 25: Map creation workflow

Flood depth raster (2016)

Figure 26 shows the flood depth raster from FEMA’s flood risk database with continuously displayed blues right after imported into ArcGIS Pro. The cells with the size of 10 ft x 10 ft contain many high values (up to 56.8 ft) for flood depths along coastal areas and where water is already present naturally (e.g. lakes, rivers). However, the focus of the study is on settlement areas and it is challenging to provide distinguishable shades of blue for different flood depths at those sites, since all values are very low compared to high flood depths in the sea. The red rectangle in Figure 26 illustrates this situation.

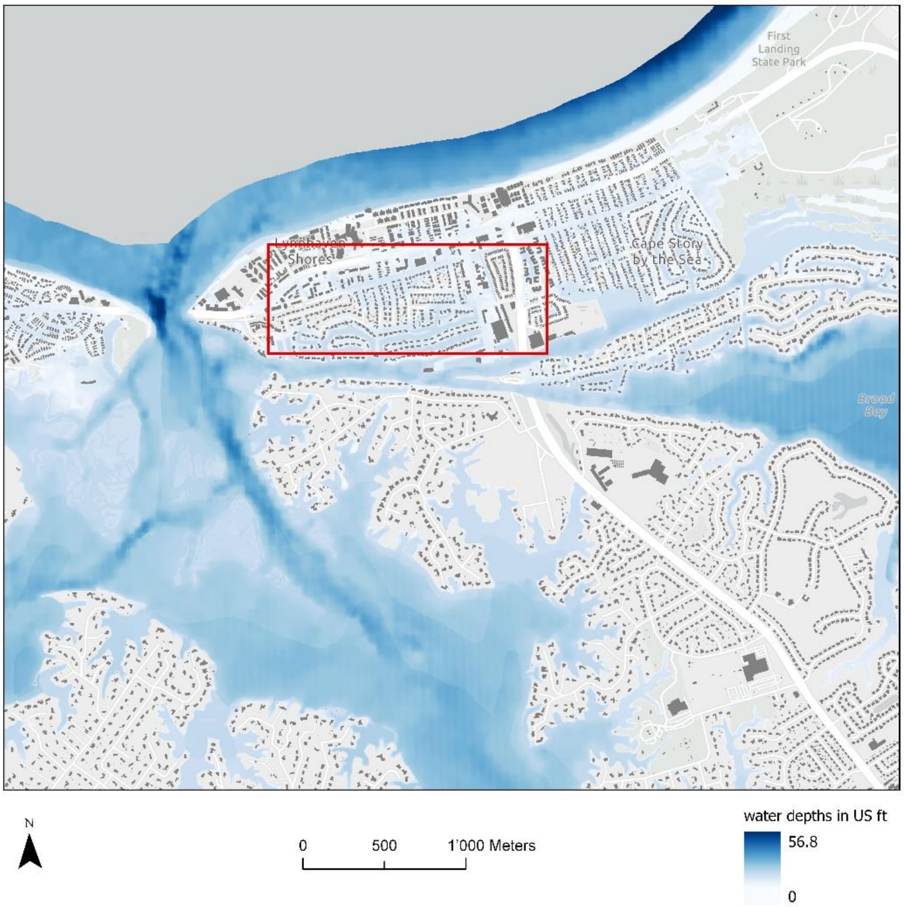

Figure 26: Flood depth raster displayed in a continuous blue schema

There are two possible solutions on how to deal with the high flood depth values outside the settlements. Firstly, by clipping raster cells in areas where normally water is present anyway. After having imported a water polygon dataset of Virginia Beach, the flood depth raster was clipped by the extent of these water polygons. Unfortunately, the water polygons were not as detailed and did not follow the real waterfronts and even cells in the settlement areas were clipped as a consequence. It is essential for the study that the flood risk visualizations appear plausible. Therefore, and as a second solution, the mask function was applied to the flood depth raster. With the mask function, it is possible to visualize only a certain range of raster cell values while values outside of the defined range are displayed as NoData-values. Thereby, only flood depth values from 0 to 14 ft are displayed in the visualizations. This range ensures a visual variability of blues for five legend entries.

The flood depth raster has so-called staircase effects that are visible at the class transitions. Those staircase effects influence the harmony of the visualization. In order to obtain a more visually appealing result, the flood depth raster was adjusted using the same procedure as in previous studies (Korporaal, 2017; Streit, 2013) as shown in Figure 27. In this procedure, a low pass filter is applied first. The low pass filter is used to eliminate extreme cells and to smooth the data by reducing local variation and removing noise. For each 3 x 3 neighborhood, the mean value is calculated and as an effect, the high and low values within each neighborhood will be averaged out (ESRI, 2016). Secondly, the 10ft x 10ft raster was processed with the resampling method bilinear interpolation to reduce the cell size to 0.1ft x 0.1ft. A resampling method changes the sizes of the raster cells and sets rules for interpolating the values of the newly sized cells. The bilinear interpolation determines the new value based on a weighted distance average of the four nearest input cell centers (ESRI, n.d.). The resulting smoothing of the data caused a reduction of the staircase effect and made the visualization more harmonious.

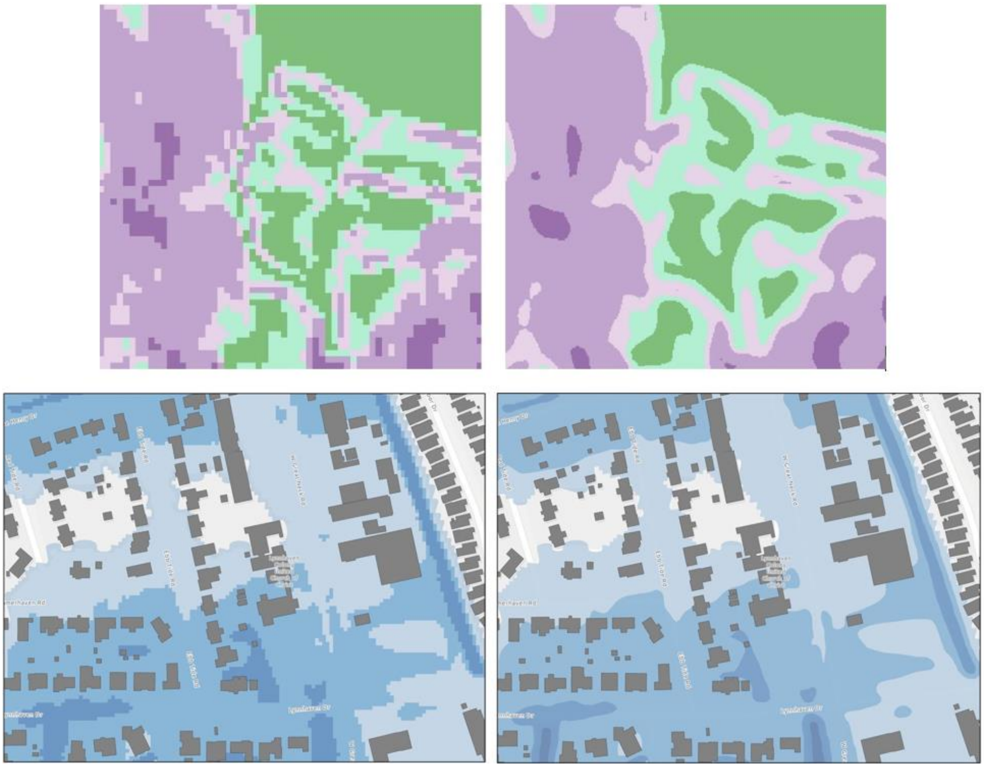

Figure 27: Smoothing procedure: Visualizations before (left side) and after (right side) (images above from Korporaal (2017))

To visualize the flood impact in 2.5D as well, the creation of water surface elevation rasters (WSE) is necessary. The cell value within a WSE raster describes the elevation of the water surface from a fixed zero elevation. In this study, the fixed zero elevation was provided in the NAVD88 vertical datum. To determine the water surface elevation, the digital elevation model (DEM) was calculated together with the depth raster resulting in a raster dataset with WSE values.

In order to display the WSE in 3D, a tool provided by ESRI's Flood Impact Analysis Solution, generates 3D flood levels out of the WSE layer and saves it as a multipatch feature.

As a result, there are two layers for the 2.5D visualizations representing the flood: On the one hand, the created 3D flood levels as a multipatch feature and on the other hand the flood depth raster. A transparency value of 50% for the 3D flood level layer ensured the recognition of the underlying flood depth raster. However, in the 2D visualization, the flood depth raster is the only layer representing the flood. This prevents a fair comparison between the two visualizations. Thus, a second overlaying layer with similar characteristics as the 3D flood levels was created for the 2D visualizations. Since multipatch features cannot be displayed in 2D, the flood depth raster was transformed to a polygon with the “raster to polygon” function. Creating a polygon out of a raster is a crude procedure and thus, the edges had to be smoothed with the function “smoothing edges” in order to get a visual appealing result. In the 2D visualization, the obtained polygon was hierarchically located above the flood depth raster as the 3D flood levels are above the flood depth raster in the 2.5D visualizations. Same color and transparency values ensure the same design result.

DEM

The Digital Elevation Model (DEM) describes the three-dimensional shape of the earth surface. It is a raster dataset and its spatial extent (=city of Virginia Beach) is represented by pixels with a 5 foot resolution (VirginiaBeachOpenGIS, 2019b). The DEM is essential to calculate the WSE. Thus, as a first step, the DEM was clipped to the same spatial extent as the flood depth raster. Afterwards, the raster values of the clipped DEM were added to the flood depths resulting in values for the WSEs as described in the section above.

Map footprints

16 map footprints of Virginia Beach were presented to each participant in the study. Since there are two groups, 32 map footprints will be generated where every 2D map footprint has its equivalent in the 2.5D visualization. A map footprint is defined here as a limited geographic area, extracted from a bigger spatial extent. For instance, the entire city of Virginia Beach represents the original spatial extent of the dataset, while a smaller polygon within this extent defines a map footprint.

Building footprints

Additionally, building footprints of the city were downloaded from the Virginia Beach GIS data webpage to visualize them in 2D (VirginiaBeachOpenGIS, 2019a). The height information of the building footprints was integrated in the corresponding attribute table and thus, it was possible to represent them in a 3D environment by extruding the building footprints according to their height information.

House markers

As a last step, markers that indicate a potential site for a house in a map footprint were created and placed. There was one house marker per map footprint. The location was defined according to the following two restrictions: Firstly, the house marker was not closer than ten meters from another building in order to avoid argumentation for not building a house because of density reasons and instead of flooding reasons. Secondly, the location of the house markers followed a trial distribution.

Consequently, certain levels of complexities were provided in a systematic way. The trial distribution is presented in the next chapter 3.3.5 and can be consulted in appendix D. In the 2.5D visualization, the house markers were also converted into 3D to ensure a similar representation of the symbol in both visualization groups.

From single layers to the visualizations

An overlay of all the described layers resulted in a single visualization. The grey basemap provided by ArcGIS, the flood depth raster, the buildings and the house markers were represented in both 2D and 2.5D visualizations. In the 2.5D visualizations, the DEM was additionally considered in order to generate 3D flood levels that lay hierarchically above the flood depth raster. Instead of a multipatch feature, the 3D flood levels were represented as a polygon in the 2D visualization. This ensured a fair comparison between the two visualization types in terms of color. On the left side of Figure 25, the hierarchy of the single layers is shown.

3.3.5 Procedure of the main experiment

After performing the BART pretest, participants were shown two consecutive information sheets with instructions on the scenario of the main study and background information on flood maps (see a complete scenario in appendix E and F). Both the pretest and the main study were implemented in PsychoPy and conducted by the participants in the corresponding software presentation mode (see more on the implementation of the study in PsychoPy in chapter 3.5). First of all, the scenario of the study was explained. Participants were asked to imagine that they wanted to build a house and 16 potential locations were predefined. However, they have not yet decided on the final location and in order to protect their future house from flooding, participants were asked to consider a flood map for their site evaluation. They were introduced to the task to rate their risk perception for each potential house location on a scale from 1 (minimum risk) to 7 (maximum risk) according to the flood visualization. The exact question was highlighted in red and was formulated as follows:

Wie riskant ist es, bezogen auf das Überflutungsrisiko, an diesem Standort ein Haus zu bauen? (English: How risky is it to build a house at this location in relation to the risk of flooding?)

Afterwards, participants were introduced to the handling and interaction with the risk scale. They also received a brief explanation of the legend entries with the flood depths and that every map footprint contains one potential house location, symbolized with a white/ grey house symbol. In addition to this, participants were informed that their response time is measured. However, it was emphasized that there is no time pressure and they should rather focus on the quality of the responses. Furthermore, it was highlighted that there are no right and wrong answers regarding their own risk perception.

As a last part, participants received the information that the flood visualizations present a flood with a 100-year return period. A brief explanation about what a 100-year return period means was provided in the information text and I was present throughout the study to answer pursuing questions that did not affect participants' performance afterwards. Then, the participants were showed a general overview of the flood visualization (2D group = 2D and 2.5D group = 2.5D) in order to get familiar with the map and to verify whether they see all the different legend colors in the visualization. As a last step before the actual main study, participants solved two training tasks and learned how to use the risk scale. If they had no more questions, they could proceed to the tasks where the responses and the time were measured.

In the main part of the study, participants solved 16 tasks without interruptions and without the possibility to ask questions. They were not able to go back and change decisions. The order of the 16 tasks was determined randomly for each participant, but followed a systematic trial distribution in terms of complexity. Within one group, four visualizations showed the house symbol in one flood depth class, eight visualizations in two flood depth classes and another four visualizations in three different flood depth classes (see appendix D). It is assumed that when the house symbol overlaps several different flood depth classes, complexity increases. When they finished the 16 tasks, a text screen appeared indicating that participants should inform me that they had completed the tasks.

3.4 Posttest

As soon as the participants had finished the main experiment, they were asked to perform the posttest. The aim of the posttest was to identify participant's strategies and to determine which factors influence their risk perception. The think aloud method was used for this purpose.

3.4.1 Think aloud

Think aloud is a method used to gain insight into people's cognitive processes (Guan, Lee, Cuddihy, & Ramey, 2006). With this method, participants solve tasks while at the same time speaking aloud what they think and do (Guan et al., 2006). Their verbalized thoughts are recorded and then used as data for further analysis (van Someren, Barnard, & Sandberg, 1994). Van Someren et al. (1994) recommend doing the think aloud during the presentation of the tasks since it is the moment where the cognitive process is activated. However, there are also negative effects when the think aloud method is used during the task solving. Firstly, speaking aloud may have a negative effect on participant's task performance. Secondly, the concentration and attention of participants might be distracted by the effort of verbalizing information. Thirdly, the verbalization could even change the way participants perceive the tasks (Guan et al., 2006). Fourthly, the response could change due to talking while competing the task. Due to those four reasons, I decided not to do the think aloud part at the same time as participants solve the visualization tasks where the responses and response time are measured. After the 16 visualization tasks, participants had three additional tasks to solve, but they were informed that neither the risk ratings nor the time were measured. The purpose of the three tasks was only to give the participants guidance to verbalize their thoughts without having the pressure to give accurate responses. Consequently, it is a kind of compromise between Guan et al. (2006), who recommended doing the think aloud retrospectively, and van Someren et al. (1994), who suggested performing it during the task solving.

3.4.2 Procedure of the posttest

After the participants had finished the 16 tasks of the main experiment, a text screen appeared providing a brief explanation about the posttest. It was emphasized that their risk ratings were not recorded anymore but in return, the participants had to solve the tasks by thinking aloud. As mentioned in the consent form, the think aloud was recorded with my smartphone. As soon as the think aloud part was done, I stopped the voice recording and the study was finished. Afterwards, I transcribed the voice records (see transcripts in appendix G).

3.5 Implementation in PsychoPy

Apart from the personal questionnaire, every component in the study requires the presentation of visual stimuli and the ability that the participants can interact with them (e.g. to rate risk perception on a scale bar). Computers have been widely used for visual and cognitive neuroscience experiments for 40 years (Peirce, 2007). According to Peirce (2007), an ideal software package for visual and cognitive neuroscience experiments should be free, open-source, user-friendly, platform-independent, able to generate stimuli on-the-fly and capable of handling new technologies.

PsychoPy was introduced by Peirce (2009) as a possible solution to meet these requirements and is presented as a free and open-source "software library written in Python, using OpenGL to generate very precise visual stimuli on standard personal computers" (Peirce, 2009). PsychoPy has several advantages. First of all, the software allows generating a window in which, for instance, some stimuli can be drawn. Once some stimuli are generated, PsychoPy lets the user specify the attributes of the stimuli such as size and location in many various units. This allows an enormously intuitive and user-friendly design of the experiment. Secondly, platform independence was one of the main goals of PsychoPy (Peirce, 2009). Computer technologies can change rapidly and PsychoPy should be able to adapt to possible changes. Thirdly, the windows are double-buffered. Any drawing commands are executed to a hidden window and are not displayed on the screen until the window.flip() command is called in the next vertical blank (VBL). A VBL signifies the end of a frame and the transition to the next (Peirce, 2009). This procedure supports the timing precision, as the period between the VBLs is extremely precise and stable. Thus, the timing precision with PsychoPy is accurate to the order of microseconds on most computers (Peirce, 2007). Additionally, the clean syntax of Python can be considered an advantage. Compared to other languages such as Matlab, Python is completely open-source and has a strong user base. However, to handle functions in PsychoPy with Python, a user must first install around 10 libraries. Nevertheless, for some years now PsychoPy offers an own built-incode-editor that has code auto completions, clear error messages and hints. Finally, the software allows a straightforward data export of the recorded measurements in most common file formats such as comma-separated values (csv) (Peirce, 2009).

As far as my present study is concerned, I chose PsychoPy because of two main advantages: First of all, I was interested in a free and user-friendly solution for sequential presentation of visualizations on a computer screen. Moreover, the participants should be able to interact with the stimuli (e.g.

assess their risk perception on a scale bar), and the time must be recorded and stored in a common file format along with the participant's response. PsychoPy provides a precise time measure with the double-buffering method and a flexible way to store results thanks to the widely used Python language. Peirce (2009) pointed out that hardware limitations can limit the temporal accuracy of the time measurements (e.g. because of the monitor or the projector). To avoid this potential disadvantage, the same hardware was used for each participant.

The specific implementation of the study in PsychoPy with its block and code components can be viewed in the file repository deposited at the Geographic Information Visualization and Analysis (GIVA) group at the University of Zurich.

3.6 Participants

The selection of participants is very important in an empirical study, as their background and characteristics can have an influence on how the tasks are solved (Wilkening, 2012). For this study, I decided to work with heterogeneous participant groups in order to obtain a more representative sample of the society. Hence, there are no requirements regarding age, education, professional experience etc. However, two requirements have to be met. Firstly, participants have to be used to work with computers and thus, no children or seniors were part of the study because the computer handling cannot be expected in any case. Secondly, since the experiment instructions are in German, participants must have a good knowledge of the German language.

A total of 34 participants took part in the study. The first two participants attended the study as test persons and are, therefore, not included in the dataset. One participant had to be excluded because it turned out afterwards that the German skills were not sufficient enough to understand the instructions without further verbal instructions in English. Another participant had to be excluded as because a misunderstanding in the study question had significantly influenced the responses. Consequently, data from 30 participants were analyzed.

3.7 Data analysis

This chapter reports on software and methods used for data analysis. In a first step, an overview of the data preprocessing for statistical analysis is provided, while the second part offers an introduction to the statistical tests is given.

Both the processing of the data and the statistics of the experimental results were done with R (version 4.0.3). The code can be viewed in the file repository at the GIVA group at the University of Zurich. Data on the BART and the main experiment were recorded by PsychoPy and saved as a csv file. These csv files were then imported into R and merged with the results from the personal questionnaire. As a result, a data structure as shown in Table 3 was processed.

Table 3: Data structure for analysis

Id	nPumps	group	Response	Reaction	Education	Gender	Age	MapUse	Cartography	GIS	Digital Maps	Flood Maps

“Id” corresponds to the unique numerical value for each participant (total 30). The result of the BART is shown in the second column called “nPumps” (see chapter 3.2.2) while “group” indicates whether a participant was assigned to the 2D or 2.5D group respectively. “Response” is the rated risk perception of the participants on the risk scale and “Reaction” presents the response time in seconds which the participants needed to make the decisions. The remaining eight columns refer to the personal questionnaire from the pretest (see chapter 3.2.1 or appendix C).

Before explaining the procedure of the statistical analysis in more detail, I would like to mention that the risk scale was converted into integer values for further analysis. Table 4 shows that “minimal risk” equals the number 1 and “maximum risk” equals the number 7:

Table 4: Transformation of risk likert-scale into integer values

Risk likert-scale in the main experiment	Numerical value
Minimum risk	1
Very low risk	2
Low risk	3
Medium risk	4
High risk	5
Very high risk	6
Maximum risk	7

In chapter 4, the three research questions are statistically analyzed one by one. For the first two research questions regarding potential differences in risk ratings and response time, descriptive statistics are presented first. Descriptive statistics such as bar plots, boxplots and mean error-bars are used to gather information about distribution of the data and to get a first impression in general. For the risk ratings of the participants and their response time, a Shapiro-Wilk test is conducted in order to investigate whether the data follows a normal distribution. The Shapiro-Wilk test is preferred for small sample sizes and is generally considered as a very powerful test (Mohd Razali & Bee Wah, 2011). For the first two research questions regarding risk ratings and response time, a Wilcoxon-Mann-Whitney test will be firstly conducted. Thus, even if a normal distribution would be present, a non-parametric test is used, as this is more robust for rather small sample sizes (Nahm, 2016). On the one hand, with a non-parametric test, it is rather unlikely to draw wrong conclusions since assumptions about the distributions are unnecessary. On the other hand, because of no assumptions about the distribution, the test has lower statistical power compared to parametric tests (Nahm, 2016). Thus, its parametric equivalent, the unpaired Student’s t-test, is conducted additionally. An assumption about the potential differences between the groups is, thus, made with both statistical tests. For the third research question, however, a linear regression is performed to investigate the influence of individual risk attitudes of the participants on their risk ratings. First, a traditional multiple linear regression model is conducted, while in a second step a linear mixed-effect model is set up. In the traditional approach, data were averaged per participant, which results in a sample size of 30. In the linear mixed-effect model, however, it is possible to avoid the reduction in sample size and use all 480 (16 risk ratings * 30 participants) data entries and at the same time take potential variability within participants into account. Thus, a linear mixed-effect approach model leads to more statistical power (Oberg & Mahoney, 2007). A significance level $\alpha = 0.05$ was set for all analyses. A deviation can be assumed non-random if it has a significance value $p < 0.05$.

The aim of the think-aloud method was to identify participant's strategies. Thus, the obtained qualitative data supplements the quantitative data evaluated for the three research questions. The voice records were transcribed (see appendix x) and then coded according to the mentioned strategies. The purposes of coding are data reduction, organization and data exploration and analysis respectively (Cope, 2016). A mentioned strategy (e.g. looking at the specific flood depth at the house location) was counted once per participant although one participant could have mentioned the same strategy several times in their think-aloud session. The reason for this is that a first participant might have mentioned the same strategy on each of the three tasks during the think aloud, and a second participant might have mentioned it only once for the very first task and clicked through the remaining two tasks without further explanations. This would distort the strategy count since the second participant probably also used his or her first mentioned strategy for the other two tasks, but decided not to specify it anymore. After the coding, a frequency table was generated indicating the count for each strategy. Afterwards, the strategy counts were divided into the 2D and 2.5D group and the differences were analyzed.

4 Results

In this chapter, the results of the study are presented. Firstly, the results of the personal questionnaire are presented in order to get a better impression of the participants. Afterwards, the results are organized according to the research questions and conclude with a chapter on the participants' strategies, which were analyzed using the think-aloud transcripts. In the subchapters 4.2, 4.3 and 4.4, descriptive statistics are shown first before results are checked for significance using statistical tests.

4.1 Personal questionnaire

As mentioned in chapter 3.6, data from 30 participants were analyzed. Out of the 30 participants, 16 (53%) were male and 14 (47%) female. The age distribution is shown in the following Figure 28:

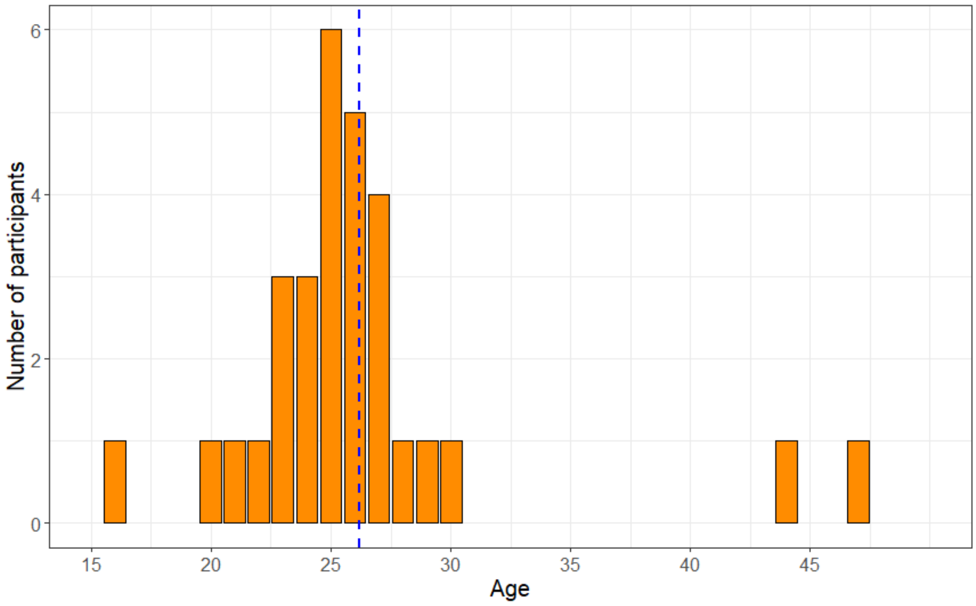

Figure 28: Age distribution of the participants

The age of the participants ranges between 16 and 47 years. The mean age is 26.2 years as indicated by the dashed blue line, while the median value is at 25 years. Figure 29 shows the age distribution for each group.

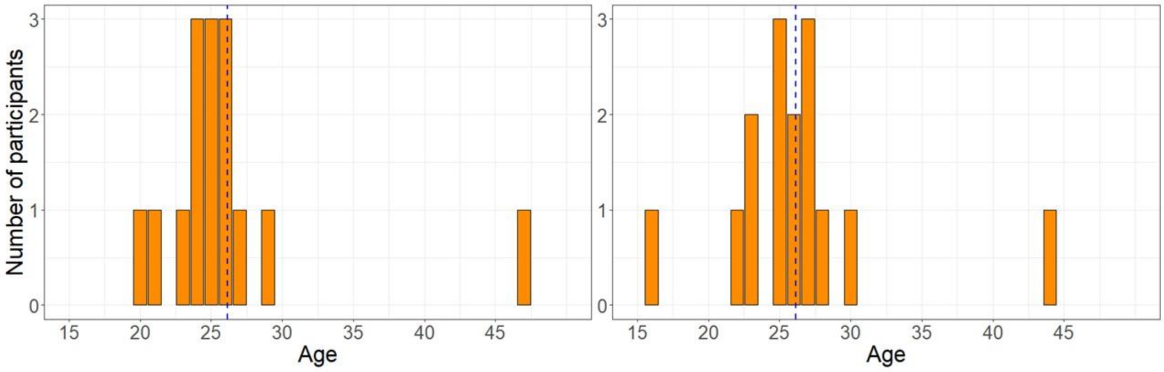

Figure 29: Age distribution 2D group and 2.5D group (2D left, 3D right)

The mean age is 26.1 years for the 2D group and 26.3 years for the 2.5D group. In both groups, there are eight male (53%) and seven female (47%) participants. No participant has indicated color blindness or red/green visual impairment.

Figure 30 shows the level of education of the participants. The major part of the participants (n=18) has a university degree. This must be considered in terms of the representativeness of the sample in relation to the society.

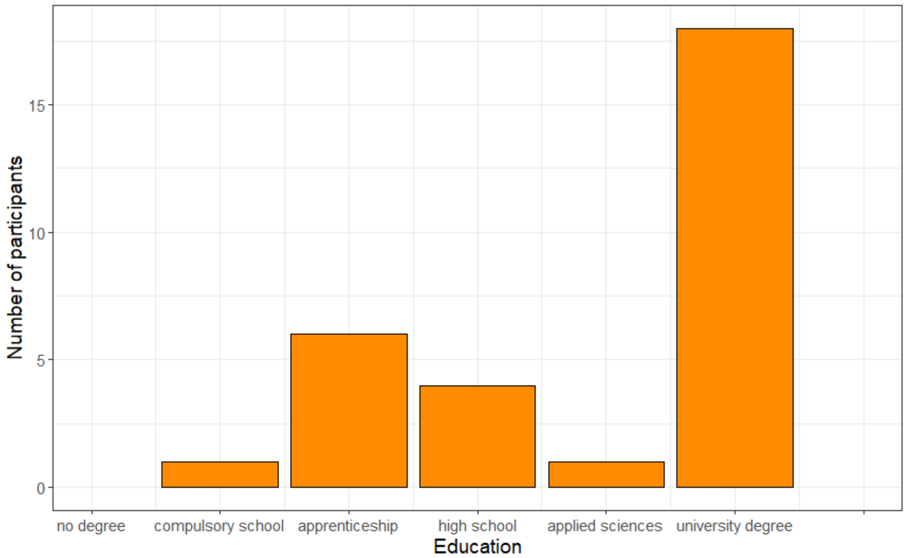

Figure 30: Level of education of the participants

The following Figure 31 illustrates how often the participants use maps for activities in their leisure time. Half of the participants (n=15) selected “rarely”, which was described as using a map for leisure activities at most once per month. Nine participants stated to use maps sometimes, which was described as using a map for leisure activities two to three times per month.

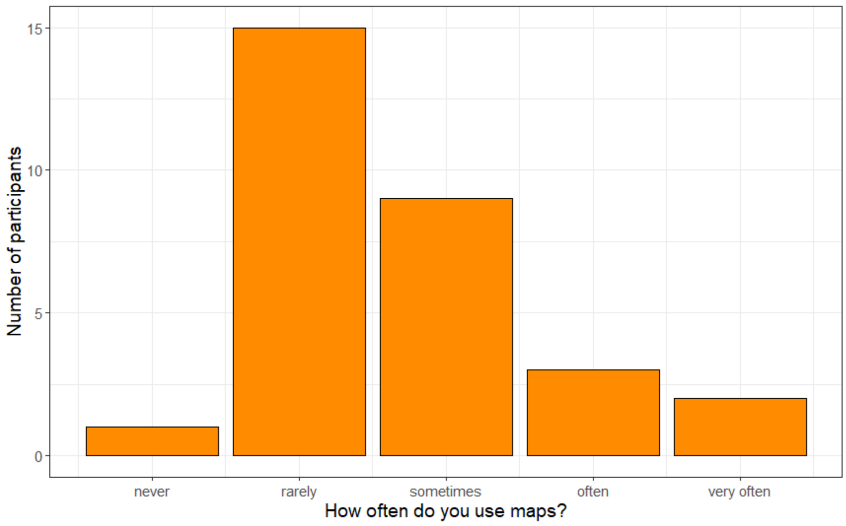

Figure 31: Information of the participants on how often they use maps for leisure activities

With the personal questionnaire, participants' experiences or prior knowledge in the fields of (A) cartography, (B) GIS, (C) digital maps and (D) flood maps were investigated as well. The results are shown in Figure 32 below.

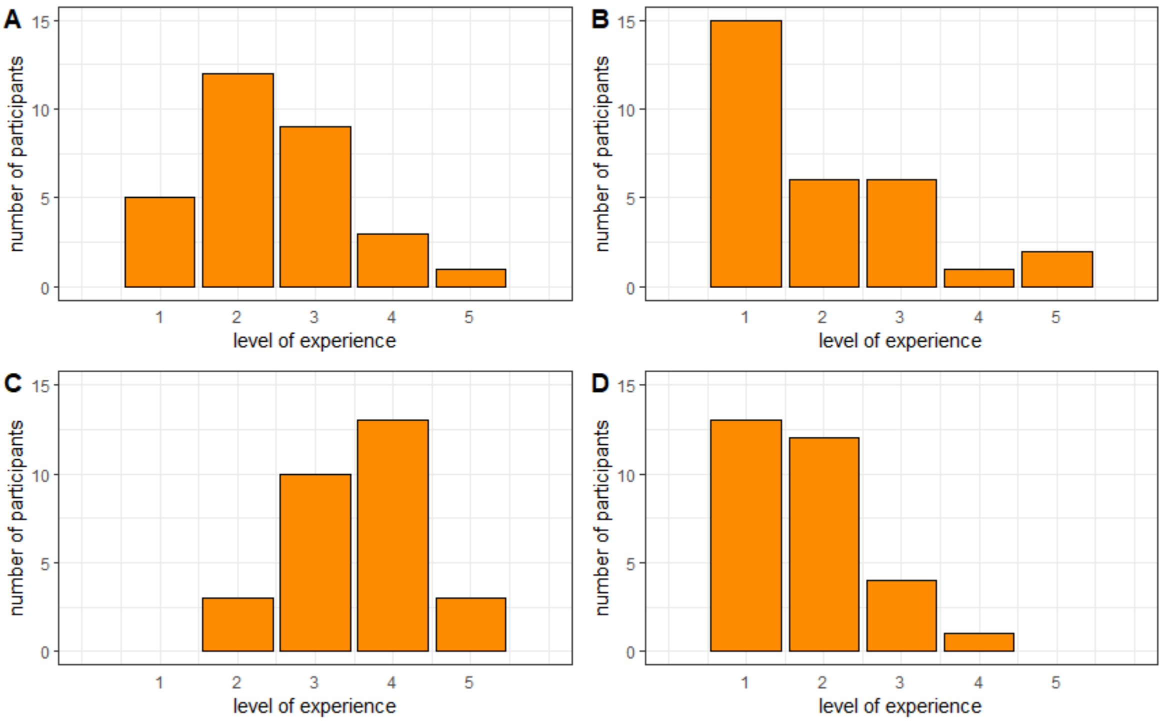

Figure 32: Previous experiences of the participants in A) cartography, B) GIS, C) digital maps and D) flood maps where 1 = "never heard of it" and 5 = "daily use"

Most of the participants were not experienced with cartography and GIS. However, a majority of the participants (n=16) indicated to have many experiences with digital maps. This is a bit surprising, since Figure 31 revealed that the participants do not use maps often in their leisure time. It might be the case that most participants only use digital maps at work or were not aware of the fact that the question of using maps in leisure time also includes digital maps. A large majority (n=25) responded that they had never heard of flood maps or had only heard of it or had seen one once. This coincides with the results of another study, which also found that many people in Switzerland are unaware of the existence of flood maps (Siegrist & Gutscher, 2006).

4.2 2D vs. 3D risk perception

In this subchapter, the results related to the first research question are explained. With the first research question, I want to investigate how people rate their risk perception when viewing a 2D flood visualization compared to a 2.5D flood visualization. First, the overall results are shown and afterwards potential influences of demographics are briefly presented.

4.2.1 Overall comparison of risk perception

Figure 33 shows the distribution of the average risk ratings per participant for 16 trials. The 2D group is displayed in orange and the 2.5D group in blue. As mentioned in chapter 3.7, the verbal risk scale is transformed to integer values for analysis. The numerical values are provided in brackets after the written scale.

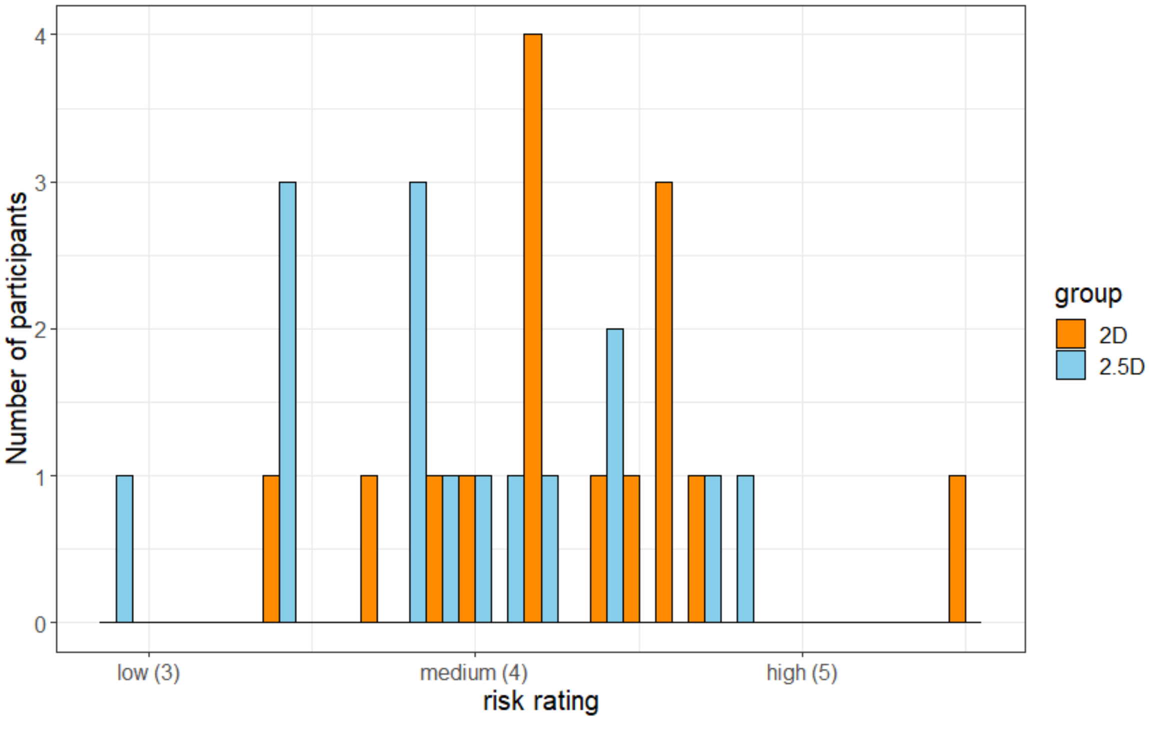

Figure 33: Risk rating distribution of 2D group and 3D group

The Shapiro-Wilk test shows that the distribution of the risk ratings in the 2D group as well as in the 2.5D group is normally distributed ($p > 0.05$). The following Figure 34 visualizes the mean risk rating together with error-bars indicating a 95% confidence interval range.

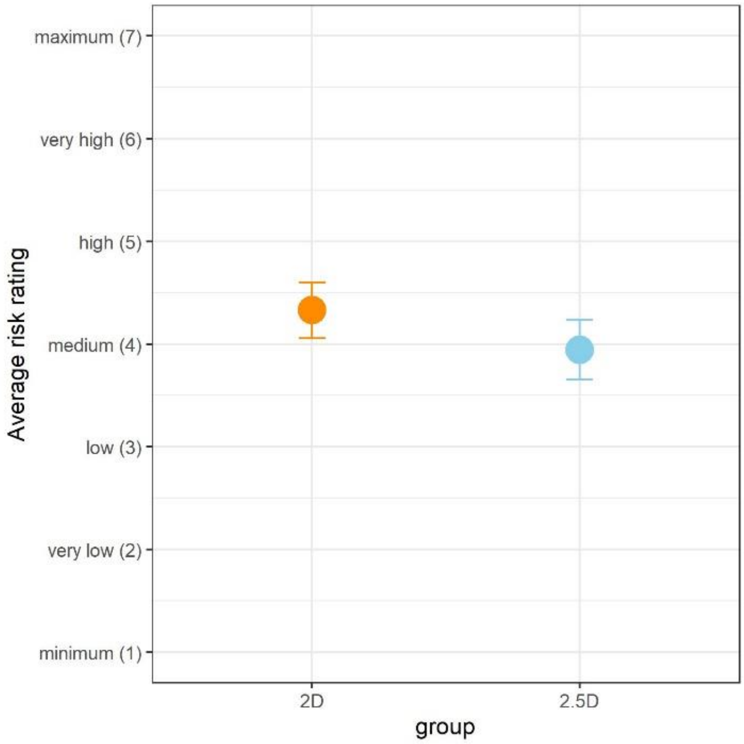

Figure 34: Mean risk ratings . Error bars indicate 95% confidence interval

The participants assigned to the 2D group rated their risk perception on average with 4.33 (standard deviation: 0.49). Participants of the 2.5D group rated their risk perception on average with 3.94 (standard deviation: 0.53). Thus, participants in the 2D group rated their risk perception on the risk scale on average above medium (4), while those in the 2.5D group slightly below. This indicates that participants were more likely to choose a higher risk rating in the 2D visualizations. Both groups do not show a wide confidence interval. Consequently, the data is not very variable. A difference between the average ratings in the 2D and the 2.5D group can be recognized but due to the overlap of the two error bars, the existence of a significant difference between the groups can be questioned. As Table 5 indicate, the Wilcoxon-Mann-Whitney test showed slightly no significant difference between the distribution of the average risk ratings of the 2D and 2.5D group for the 2D and 2.5D visualizations ($p = 0.0635 > 0.05$). However, the t-test showed a slightly significant difference between the groups ($p = 0.0486 < 0.05$). Thus, it can be concluded that participant who viewed on a 2D flood visualization rated their risk perception higher than participants who viewed on 2.5D flood visualization, but the significance of the difference can be debated.

Table 5: Wilcoxon-Mann-Whitney and t-test for differences in risk rating

Wilcoxon-Mann-Whitney		**t-test**	
Z-score	p-value	t-value	p-value
1.8703	0.0635	2.0627	0.0486

4.2.2 Risk perception based on demographic information

Based on demographics, this subchapter aims to deepen the knowledge of where differences could have occurred. It is important to mention that an analysis of differences in risk perception based on demographic information is beyond the scope of the first research question. Thus, potential differences between demographic groups are not tested for significance, but are described.

Figure 35 on the next page visualizes the risk perception mean with 95% confidence intervals error-bars of the 2D and 2.5D flood visualizations between demographic groups. The order follows the questions of the personal questionnaire, which was conducted before the main experiment. Firstly, male and female were differentiated. Secondly, a differentiation between participants with and without a university degree was done. In the personal questionnaire, participants were also asked about their use of maps in their leisure time and their experiences in the fields of cartography, GIS, digital maps and flood maps. Table 6 shows how participants were divided into the "experienced" and "inexperienced" group. The number in brackets in the "split-up" column indicate the level of experience as presented in Figure 30, Figure 31 and Figure 32. The main split criteria into the "experienced" and "inexperienced" group was that both groups have approximately equal numbers of participants. Finally, it is important to consider that the level of experience is self-reported by the participants. It is possible that a participant over- or underestimate his/her skills in particular fields.

Table 6: Split-up criteria for demographic groups

Demographic group	Split-up	Number of participants in each demographic group (brackets: number of participants from 2D/2.5D group)
Gender	female/male	14 females (7+7) / 16 males (7+7)
University	Degree/ no degree	18 degrees (9+9) / 12 no degree (6+6)
Map use	experienced (3,4,5)/ inexperienced (1,2)	14 exp. (9+5) / 16 inexp. (6+10)
Cartography	experienced (3,4,5)/ inexperienced (1,2)	13 exp. (9+4) / 17 inexp. (6+11)
GIS	experienced (2,3,4,5)/ inexperienced (1)	15 exp. (9+6) / 15 inexp. (6+9)
Digital maps	experienced (4,5)/ inexperienced (1,2,3)	16 exp. (8+8) exp. / 13 inexp. (7+6) *
Flood maps	experienced (2,3,4,5)/ inexperienced (1)	17 exp. (6+11) / 13 inexp. (9+4)

* NA value for this question in one participant's personal questionnaire

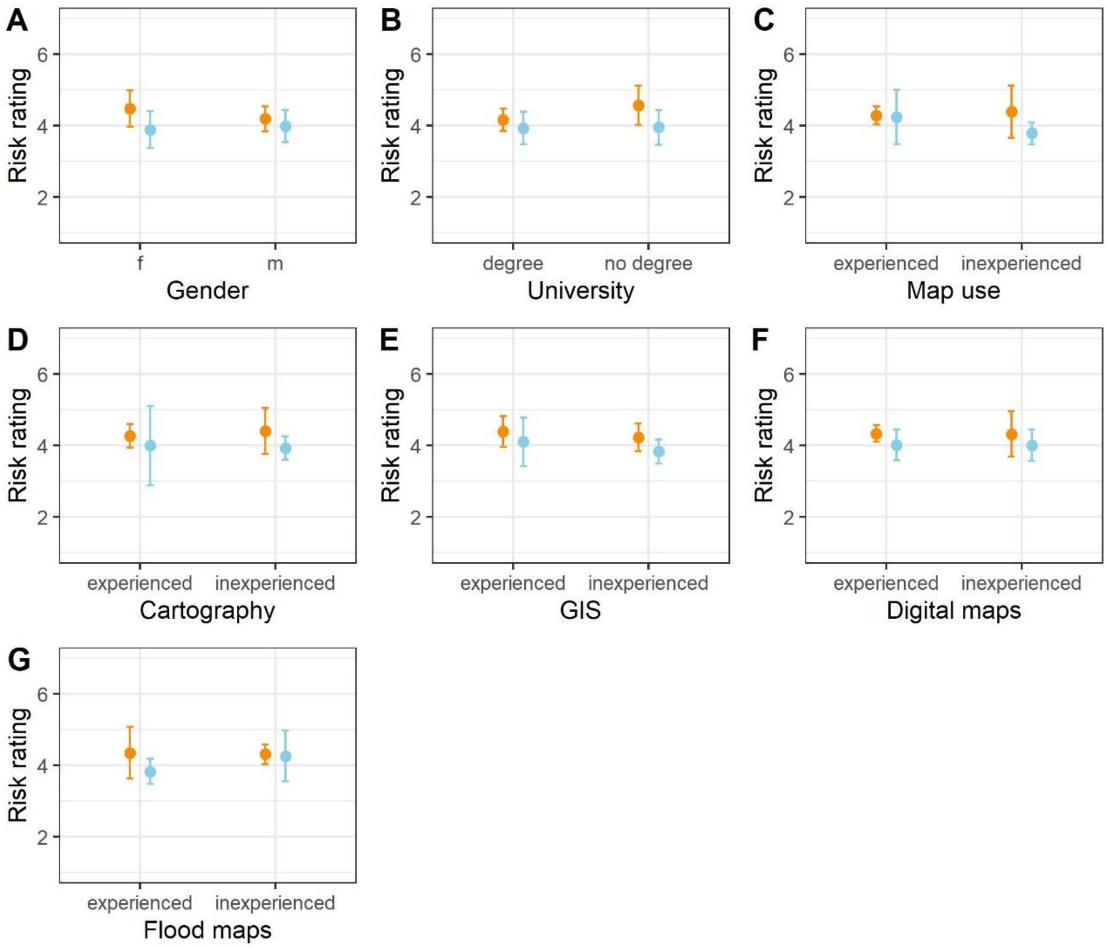

Figure 35: Risk rating error bars regarding different demographic groups (95% confidence)

Plot A illustrates that female participants rated their risk perception in 2D flood visualizations higher than male participants did. However, the larger range of the error bars indicate a bigger variability in risk perception of female participants compared to male participants. Plot B reveals that the difference in risk perception between 2D and 2.5D flood visualizations seem to be bigger for participants without a university degree than for participants holding a university degree. However, the overlapping error-bars between 2D and 2.5D visualizations for non-university-degree holder indicate that the difference is probably not that big. There is a large data variability in 2.5D flood visualizations for participants experienced in map using (plot C), cartography (plot D), GIS (plot E) and digital maps (plot F). This is especially interesting since there is a rather low variability for the 2D flood visualization. Just the opposite applies to participants with lower experience in map-use, cartography, GIS and digital maps. They seem to rate their risk perception more variable with 2D rather than 2.5D flood visualizations. The same applies to participants with experiences in flood maps (plot G). However, a main reason for these differences could be the comparatively small amount of data in the groups (e.g. only four participants in the experienced cartography group for 2D visualizations), which inevitably leads to a larger confidence interval.

4.3 2D vs. 3D response time

In this subchapter, the results related to the second research question are presented. With the second research question, I wanted to investigate what the drivers for possible differences in response time between a 2D and a 2.5D flood visualization are. Firstly, the overall results are shown and afterwards potential influences of demographics are briefly presented.

4.3.1 Overall comparison of response time

Figure 36 shows the distribution of the average response time per participant for 16 trials. The 2D group is displayed in orange and the 2.5D group in blue.

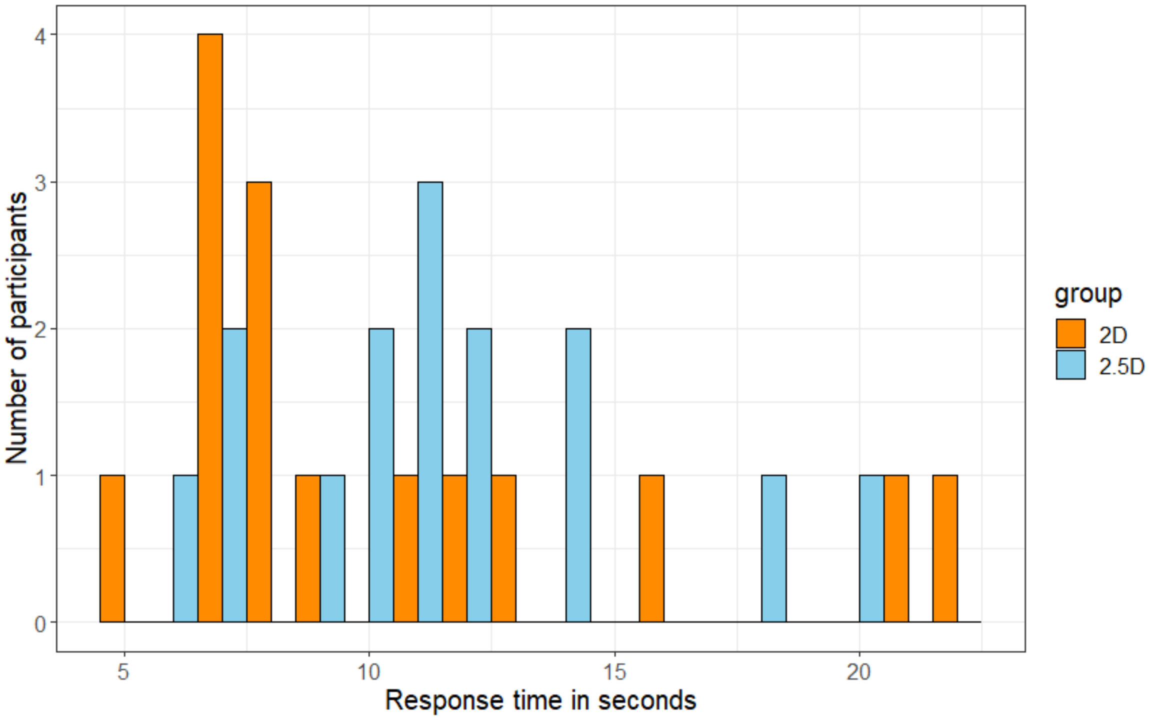

Figure 36: Response time distribution of 2D group and 3D group

A Shapiro-Wilk test shows that the distribution of the response time in the 2D group are not normally distributed ($p < 0.05$). However, the response time distribution in the 2.5D group is normally distributed ($p > 0.05$). The following Figure 37 shows the boxplots of the average response time per participant and group. In contrast to the previous subchapter, boxplots are shown here instead of mean error-bars. This is due the issue that the response time values of the 2D group show a considerable skewness in the distribution and under these assumptions, boxplots can visualize more valuable information. The visualization of mean error-bars is omitted because the skewed data leads to a wide 95% confidence interval, which makes the visualization harder to interpret.

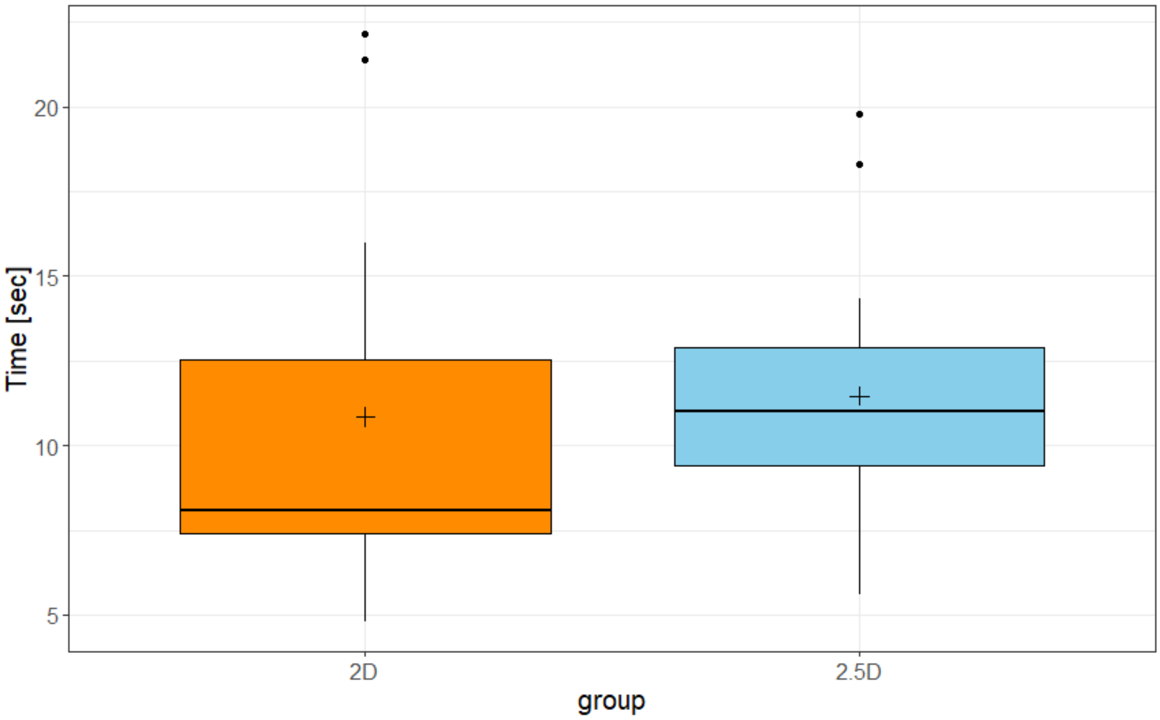

Figure 37: Boxplot of overall response time in the 2D group and 2.5D group

A slight difference between the average response time per participant for the 2D and the 2.5D group can be detected. However, the difference is likely to be rather small, since the interquartile range for both groups is in a similar range. The median value for the 2D group is at 8.1 seconds and for the 2.5D group at 11 seconds. In the 2D group, the 1st quartile is at 7.41 seconds and the 3rd quartile at 12.52 seconds. The range between the quartiles in the 2.5D group is slightly smaller with the 1st quartile at 9.41 seconds and the 3rd quartile at 12.88 seconds. The response time in the 2D group ranges from 4.78 to 22.14 seconds (defined as an outlier) and for the 2.5D group from 5.61 to 19.78 seconds (defined as an outlier). However, and to maintain consistency with previous descriptions, the mean is visualized in the figure with a plus symbol. The participants assigned to the 2D group needed on average 10.84 seconds (standard deviation: 5.27 seconds) to rate their risk perception. Participants of the 2.5D group needed on average 11.47 seconds (standard deviation: 3.88 seconds) to decide on their risk perception. According to the Wilcoxon-Mann-Whitney test, this difference is not significant ($p = 0.4564 > 0.05$), which is shown in Table 7. Although the average risk ratings in the 2D group are not normally distributed, a t-test is conducted additionally in order to be consistent with the first research question in terms of data analysis methods. The t-test also showed no significance ($p = 0.7131 > 0.05$). As a conclusion, the range of response time values for participants who viewed on a 2D flood visualization was larger but on average, they needed slightly less time than participants from the 2.5D group.

Table 7: Wilcoxon-Mann-Whitney and t-test for differences in response time

Wilcoxon-Mann-Whitney		t-test	
Z-score	p-value	t-value	p-value
-0.7673	0.4564	-0.3718	0.7131

4.3.2 Response time based on demographic information

The difference in response time of the participants between 2D and 2.5D flood visualizations is not significant. However, and as done in chapter 4.2.2, a brief reporting on demographic differences is provided. This subchapter aims to deepen the knowledge of where differences could have occurred. Similar as in chapter 4.2.2, potential differences between demographic groups are not tested for significance, but are described.

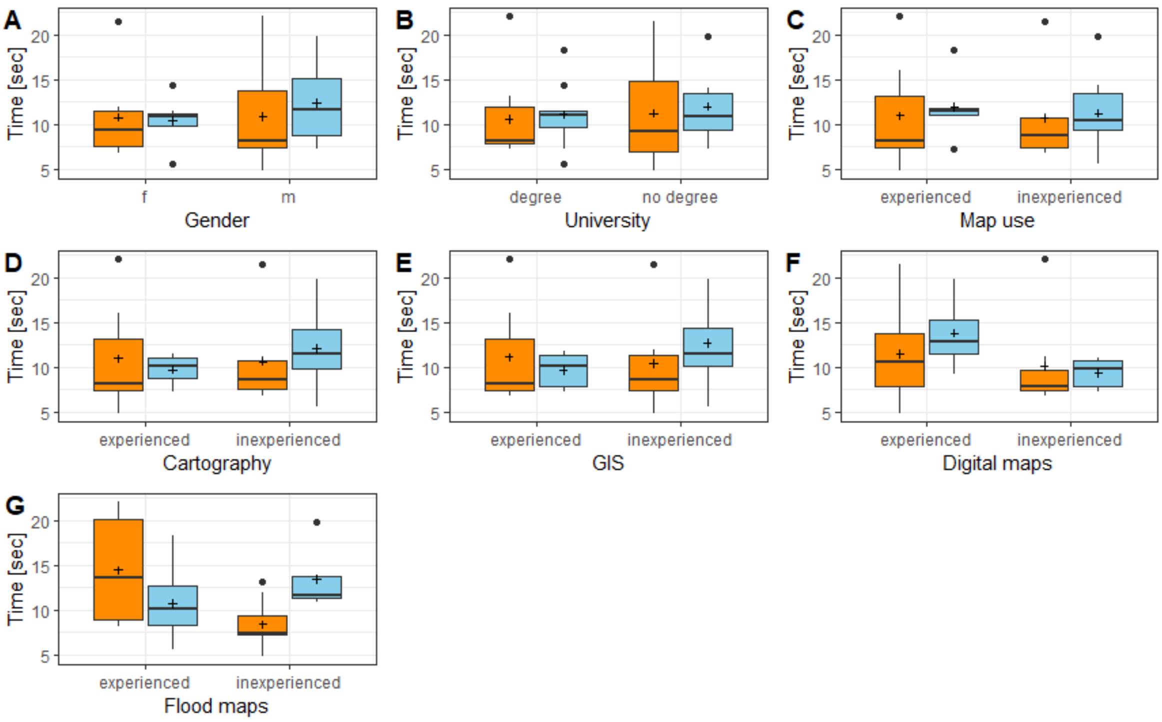

Figure 38: Boxplots of response time regarding different demographic groups

Figure 38 shows that in every demographic group, the median value for response time for the 2.5D flood visualization is higher than the median for the 2D flood visualization, except for the flood maps experienced group (plot G). However, when considering the mean, the differences are not ambiguous anymore. Plot A shows that response time values of male participants are slightly more scattered than those of female participants. The same issue can be observed with the values of participants with no university degree compared to participants with a university degree (plot B). Differences among the participants in the experiences of using maps (plot C) and experiences in cartography, GIS and digital maps (plot D, E and F) show quite similar data distributions in response time for 2D and 2.5D flood visualizations. In general, it is difficult to identify differences among demographic groups in response time. However, inexperienced flood map readers (plot G) seem to need more time to make a decision with the 2.5D flood visualization than with the 2D flood visualization.

4.4 Effects of risk attitudes on visualization risk ratings

In this subchapter, the results related to the third research question are presented. With the third research question, I wanted to investigate how people's individual attitudes towards risk influence their risk perception. First, a traditional multiple linear regression is conducted, while in a next step the results of the linear mixed-effect model are presented.

4.4.1 Overall influence of individual risk attitudes on risk ratings

For a first impression of the data, a scatterplot was generated as shown in Figure 39 without considering the separation in two groups. Average risk ratings are displayed on the y-axis with their integer values in brackets that were used for the analysis. On the x-axis, risk attitude describes the risk index of a participant according to BART as the risk measure. As described in more detail in chapter 3.2.2, risk attitudes are represented by the average number of pumps a participant has performed excluding the exploded balloons.

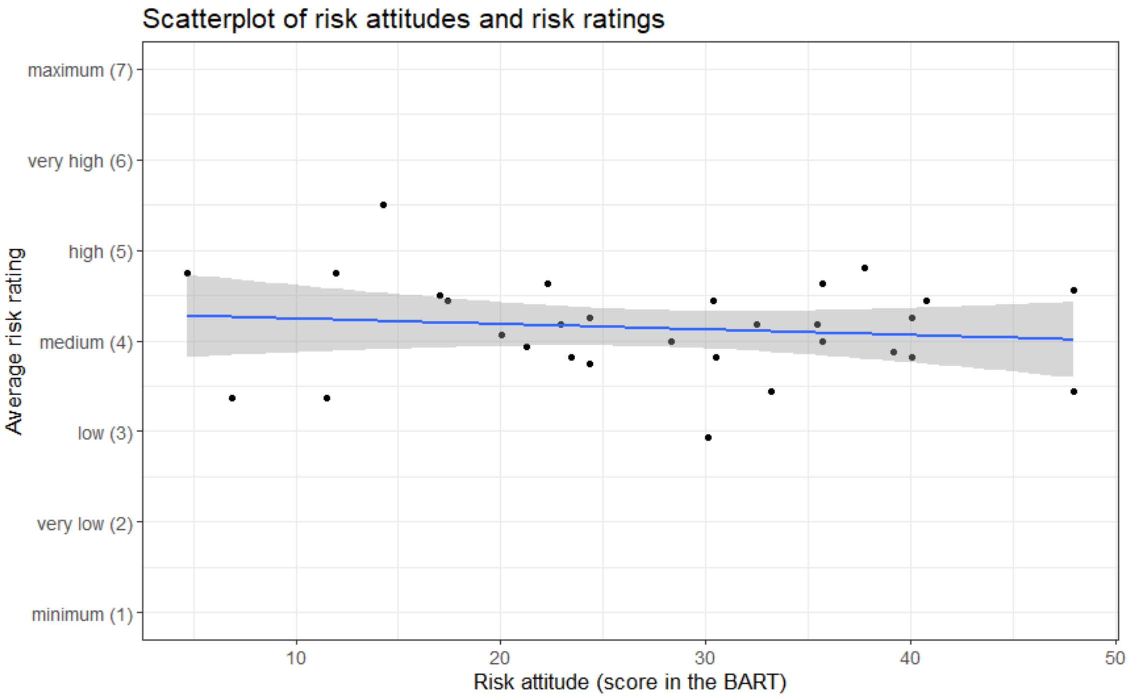

Figure 39: Scatterplot of risk attitude and risk ratings

Figure 39 shows a very weak, rather negative linear association between risk attitudes and the risk ratings of the participants. At first glance, there seem to be also a few outliers at both ends of the graph. The result suggests that individual risk attitudes probably do not affect the risk ratings very strongly. However, a multiple linear regression is performed in a next step to investigate how much of the variation in the risk ratings can be explained by the predictors. The predicting variables are risk attitude and the group (2D and 2.5D).

Before the results of the multiple linear regression are presented, it is important to mention the risk attitude distribution among the participants between the groups. Participants were assigned to the 2D and 2.5D group according to their age and gender, but not due to their measured risk attitude with the BART. Thus, it is necessary to be aware of potential differences in risk attitudes between the groups in order to provide an appropriate discussion of the results. Especially for the conclusion of the first research question, it is essential to take risk attitudes differences between the groups into account. For instance, if the influence of risk attitude on risk ratings would be rather strong and there are more risk-seeking participants (higher scores in the BART) in the 2.5D group, the higher risk ratings of the 2D group cannot only be explained by the visualizations. Then, the risk attitudes of the participants would have played a role in their assessment of risk ratings. Figure 40 shows the density distribution of risk attitudes between the 2D and 2.5D group.

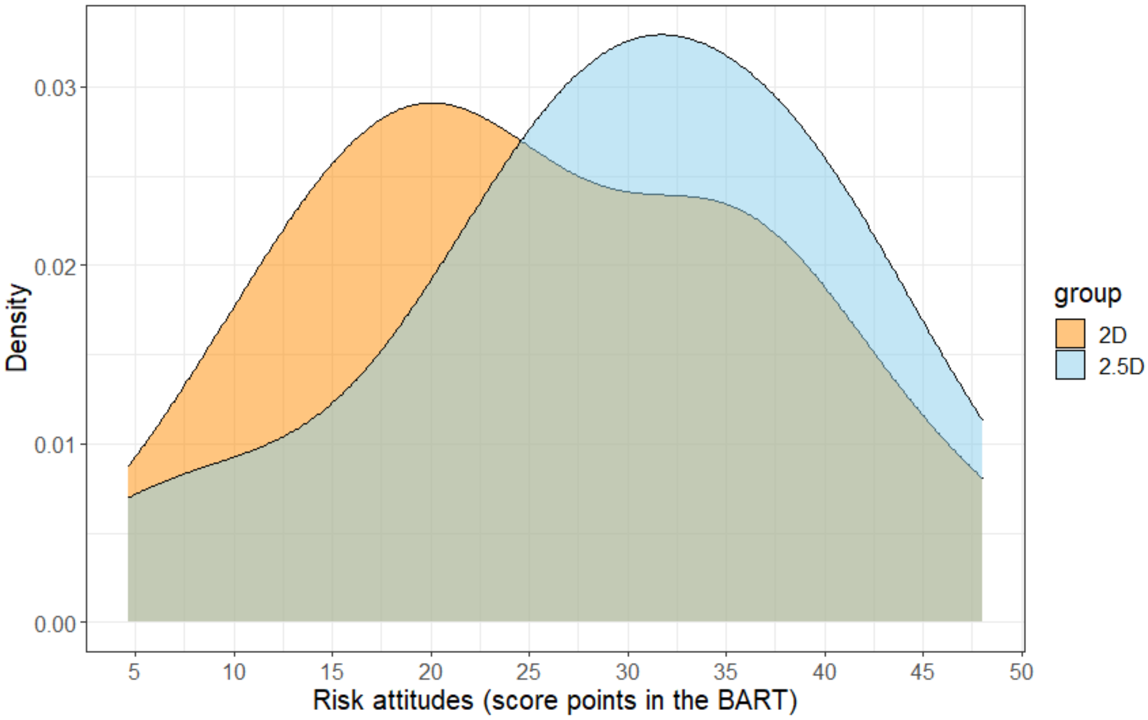

Figure 40: Risk attitude distribution between the 2D and 2.5D group

It can be recognized that the participants in the 2D group scored less points in the BART than the participants in the 2.5D group. This leads to the assumption that participants who viewed at 2.5D flood visualizations are in tendency more willing to take risks. Nevertheless, a conducted Wilcoxon-Mann-Whitney test showed no significant difference of participant's risk attitudes between the two groups ($p = 0.3735 > 0.05$).

However, it is even more important to take the slightly different risk attitudes distributions between the groups into account, if the risk attitude is an influential predictor of risk ratings. The result of the multiple linear regression with the aim to find out whether risk attitudes have an effect on risk ratings is presented in Table 8.

Table 8: R-output of the multiple linear regression model

		Response	
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.42	3.90 – 4.94	**<0.001**
group [2.5D]	-0.37	-0.76 – 0.02	0.063
nPumps	-0.00	-0.02 – 0.01	0.681
Observations	30		
R^2 / R^2 adjusted	0.137 / 0.074		

As already noted in chapter 4.2.1, the average risk ratings per participant in the 2D group (4.42) is higher than that of the 2.5D group (4.42-0.37=4.05). A certain effect of different dimensionality of the visualizations on risk ratings can, therefore, also be recognized in the multiple linear regression, although it is barely significant as well (p = 0.063 > 0.05). However, the risk attitude (represented by nPumps) has hardly any effect on the risk ratings (-0.0035). The multiple linear regression, thus, confirms the extremely slight negative linear association between risk attitudes and risk ratings showed in the scatterplot of Figure 39. Thus, the estimated effect of the risk attitude on risk ratings, adjusted for group, does not fit the significance threshold (p = 0.681 > 0.05). In summary, the regression model with the two predictors group and risk attitude only explains 7.4% of the variation in the data indicated by the R^2 adjusted. This leads to the assumption that risk ratings are rather more driven by other factors than individual risk attitudes and group assignment. In order to verify whether the assumption for a linear regression is met, diagnostic plots of the multiple regression model are shown below in Figure 41. The residuals vs. fitted plot on the top left shows no distinct patterns of spread residuals, which indicate the absence of non-linear relationships. On the top right, the normal Q-Q plot shows that the residuals are normally distributed and the scale-location plot in the bottom left indicates that the residuals appear randomly spread (homoscedasticity). Overall, it is possible to detect some outliers in the residuals vs. leverage plot, but there are no influential cases. Thus, it can be assumed that the model meets the assumptions of a linear regression and works well for the data.

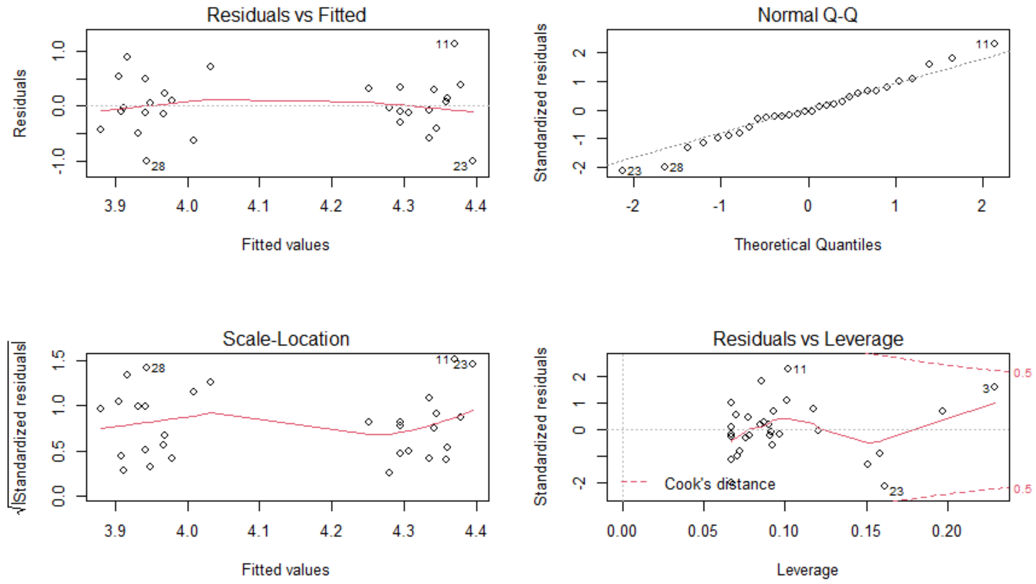

Figure 41: Diagnostic plots of the multiple linear regression model

In a next step, a linear mixed-effect model was set up. As described in chapter 3.7, a linear mixed-effect model is able to consider all 480 risk ratings. Additionally, it takes random effects such as the potential variability in risk ratings within participants into account. Thus, more statistical power is gained. Table 9 presents the output of the linear mixed-effect model:

Table 9: R-output of the linear mixed-effect model

		Response	
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.05	3.50 – 4.60	**<0.001**
group [2D]	0.37	-0.00 – 0.75	0.052
nPumps	-0.00	-0.02 – 0.01	0.677
Random Effects			
σ^2	2.50		
$\tau_{00\ Id}$	0.11		
ICC	0.04		
N_{Id}	30		
Observations	480		
Marginal R^2 / Conditional R^2	0.014 / 0.056		

The linear mixed-effect model shows the same estimated effect of groups on risk ratings as the traditional multiple linear regression approach (0.37). Likewise, the effect of risk attitude on risk ratings is also estimated with an extremely flat slope (-0.00), indicating nearly no positive or negative linear association. This is confirmed by the statistically non-significant effect of risk attitude on risk ratings ($p = 0.677 > 0.05$). The similarity to the multiple linear regression can be explained by the fact that the variance of the random effects ($\tau_{00\ Id} = 0.11$) is rather small in relation to the total variance of residuals ($\sigma^2 = 2.5$). Thus, differences of risk ratings within participants explain only 4% of the variance or in other words, 96% of the variance in outcome is not explained by the random effects. Finally, the linear mixed-effect model explains 1.4% of the variance without considering random effects (marginal R^2) and 5.6% by taking random effects additionally into account (conditional R^2). These low R^2-values lead to the assumption that risk ratings are weakly influenced by the individual's risk attitudes.

Figure 42 shows the plot of the linear mixed-effect model results. Given the provided data, the model predicts the values of average risk ratings. For instance, a new participant in the 2.5D group scored 15 points in the BART that defines his or her risk attitude. According to the model, this new participant will rate his or her risk perception on average as medium (4).

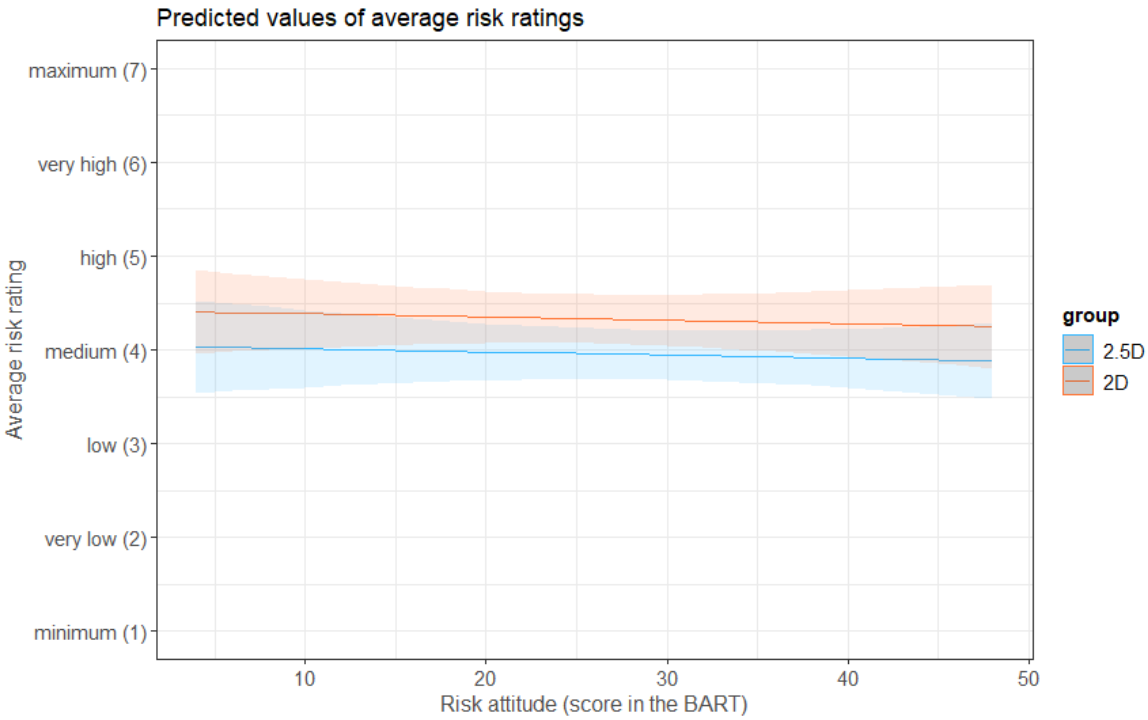

Figure 42: Linear mixed-effect model: predicted values of average risk ratings

Consequently, the model graph visualizes how much the average risk ratings change as risk attitudes increases. It can be further recognized that the graph is also accompanied by a relatively wide confidence interval band. A wider confidence interval indicates a higher variability in the data. Furthermore, the wider band at both ends of the graph is probably a result of smaller sample size since there are not many participants with extreme risk attitudes (very low or very high scores in the BART). Additionally, it can be seen that the confidence interval bands of the 2D and 2.5D group overlap with each other. This overlap confirms the founded results of the first research question that there is a difference in average risk ratings between the groups but not an extremely large difference.

Referring back to the question how individuals' risk attitudes influence participant's risk ratings, it can be stated that the influence is weak. Figure 42 shows that a quite large change in the BART scores leads to only a very small decreasing change in average risk ratings. Thus, individuals' risk attitudes cannot be identified as an influential factor on participant's average risk ratings.

4.4.2 Effect of demographics on influence of risk attitudes on risk ratings

In the previous subchapter, it was highlighted that the relationship between risk attitudes and risk ratings is weak. In this subchapter however, the influence of demographics on the effect of risk attitudes on risk ratings is analyzed and reported. More specifically, it investigates how gender and the experience in using maps influences the rather weak relationship between risk attitudes and risk ratings.

Therefore, the linear mixed-effect model was extended firstly by gender as a moderator. The specific aim was to find out if and how gender changes the effect of risk attitudes on risk ratings. It was found that gender does not significantly influence this effect ($p = 0.349 > 0.05$). Figure 43 shows the plot of the conducted linear mixed-effect model. It can be recognized that the linear association between risk attitude and average risk rating is still very weak and rather negative. Compared to the linear mixed-effect model without gender as a moderator, the difference between the groups is bigger, indicated by the larger distance between the graphs. In summary, the weak effect of gender as a moderator can be confirmed since the plot looks quite similar to Figure 42 without any moderators.

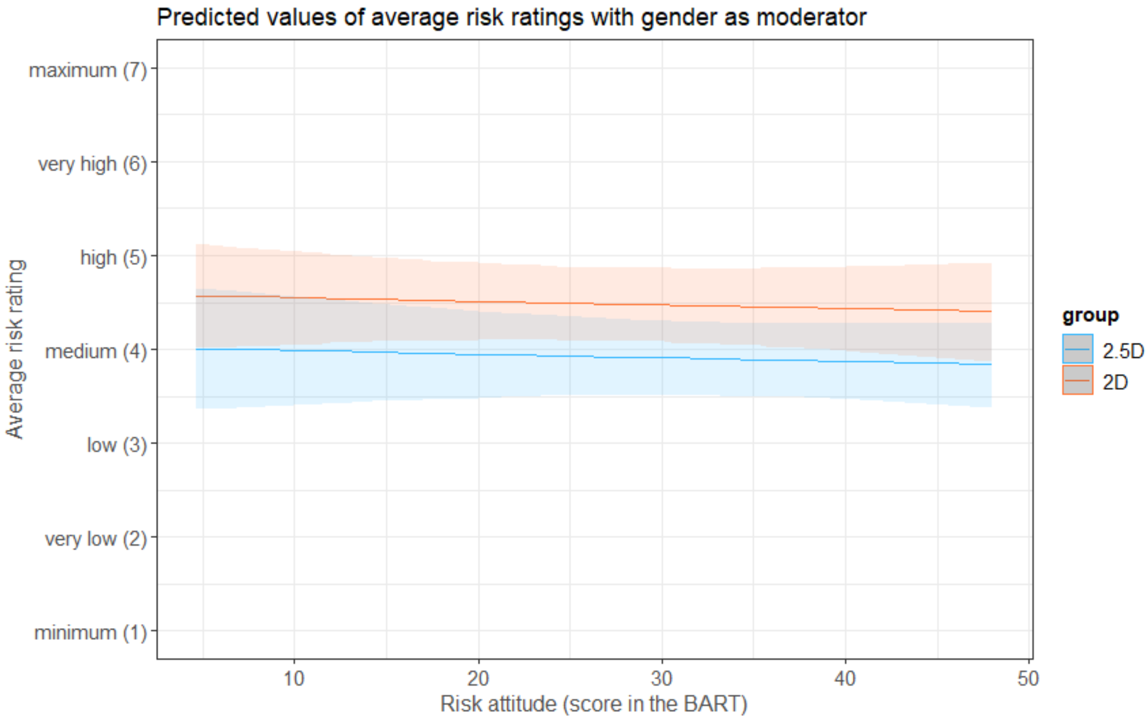

Figure 43: Linear mixed-effect model: predicted risk ratings with moderator gender

A similar procedure was conducted in order to investigate whether experiences in using maps changes the effect of risk attitudes on risk ratings. In the personal questionnaire at the beginning of the study, participants were asked about their use of maps in their leisure time on a scale from "never" to "very often". For data analysis purposes, the values were transformed into integer values. Furthermore, and in order to reduce a potential correlation between the predictors of the model, the values of the self-reported map-use experience were mean-centered. In Figure 44, those self-reported and mean-centered answers by the participants are implemented as a moderator variable into the linear mixed-effect model. The visualized graphs show a weaker relationship and virtually no negative linear association between risk attitude and average risk ratings compared to the previous plotted linear mixed-effect models.

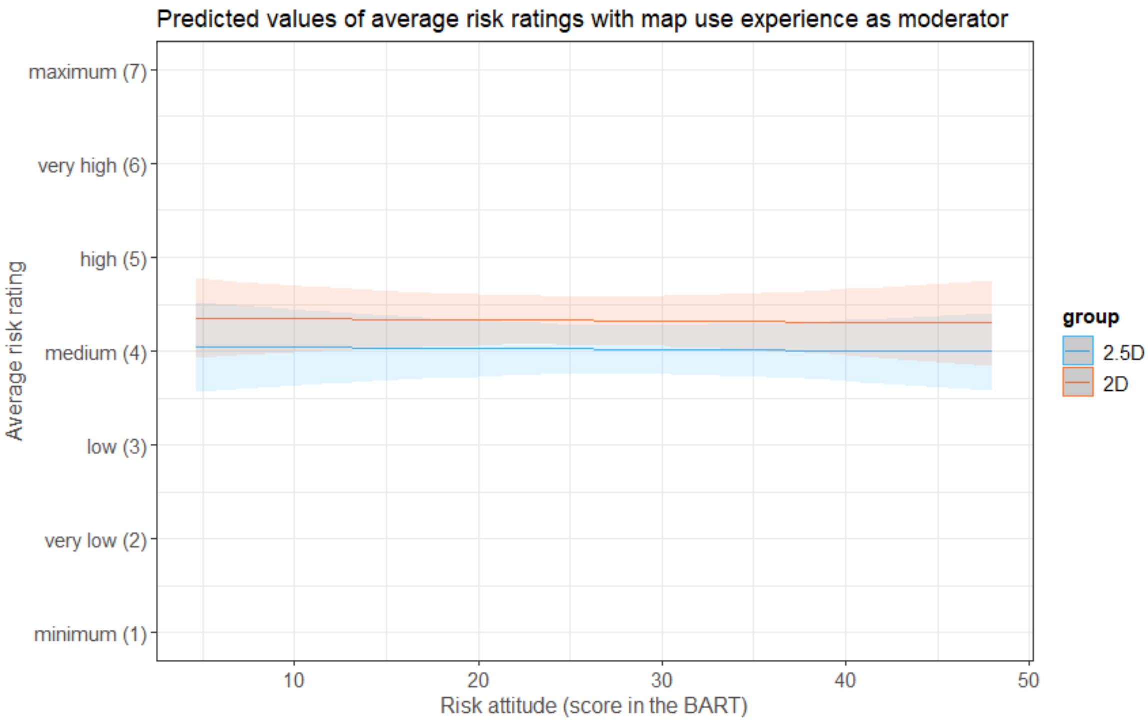

Figure 44: Linear mixed-effect model: pred. risk ratings with moderator map use experience

This leads to the assumption that experience in using maps have an influence on the effect of participants' risk attributes on their risk ratings. When participants' experience in using maps is taken into account, the effect of their risk attitudes on the risk ratings seems to be smaller. However, this influence is not statistically significant ($p = 0.121 > 0.05$).

4.5 Mentioned strategies in the think aloud

4.5.1 Overall strategies

As explained in chapter 3.7, various strategies of the participants were identified and coded based on the think-aloud transcripts. In this subchapter, a general overview over the applied strategies is provided. Since the study was conducted in German, all exemplary statements mentioned in the bullet points are translated from German into English. The frequency table is showed in Figure 45 on the next page where the counts are already divided into the 2D and 2.5D group.

In the think-aloud part of the study, nearly all participants mentioned that they looked at the specific flood depth classes at the potential house site (93.3%).

- First, I looked at the flood depth. The house is in 0.6-1.0m flood depth. [P3]
- Here I rated it as very high because it is completely in the normal blue area. [P5]
- Relatively high risk because it is situated in a zone where the flood depth is 1.5m. [P13]
- Here it is a slightly darker blue…but not dark blue. That is why I would still rate it as medium risk. [P24]

It is highly probable that every participant took the flood depth at the house site into consideration for estimating their risk perception, but did not mention it in the think-aloud part. The 100-year return period of the visualized flood was barely mentioned by the participants (13.3%). However, approximately two out of three participants did not only focus on the flood depth at the house location but also on the flood depths of its close surroundings (63.3%). If a house was not in a high flood depth class but surrounded by darker shades of blue indicating higher flood depths, participants perceived the risk as higher.

- […] and it is quite close to the very deep water up to 2m. [P5]
- There, I actually see that it is not dark blue anywhere nearby, and that is why I classify that as lower or medium. [P16]
- […] is actually in a risk area where [it] is low risk, but by the hazard that you can see that it is near from the dark blue, I then decided to go high. [P27]

As described in chapter 3.3.5, some hypothetical houses were located at the transition of two or three different flood depth classes. In total 53.3% of the participants explicitly mentioned this fact and saw these overlaps as a reason to rate the risk of building a house at this location higher.

- So here, it is difficult because the pictogram is in several different colors. There, I have simply taken something in the middle. [P2]
- So, I took medium because it is actually bordering to a place with very little water, but also to a place with a lot of water. [P14]
- […] and the house is just right on the border with a rapid increase in flow depths, so I would pick very high risk there. [P17]

The last statement also indicates that some participants have thought about the topography and the flow directions of the water. Approximately every fourth participant mentioned the topography and tried to derive where the water comes from (26.6%). They used mainly the inset map and the flood depth gradients as a main source to mind-map the terrain.

- In the next map I also looked at the big overview to see where the water comes from and where it is really deep. [P13]
- I see it is rather flat, so the gradients are not that big and so I assume first that there are lower hazards. [P17]

- It goes up a bit… so it looks like it is more on a slope… that is why I thought it [the water] might be more likely to run off. [P21]

I would like to present also some findings regarding strategies based on the marginalia of the visualizations (e.g. inset map, legend). As mentioned in the third paragraph of this subchapter, approximately two out of three participants took flood depth classes of the house location's closer surroundings into account. Sometimes the main map was not sufficient and 40% of the participants mentioned during the think-aloud part that they considered the inset map with its smaller scale. In addition, some participants mentioned that they followed the strategy to consult even at very first the inset map to get a general impression of the flood situation before focusing more on the specific house location.

- When I look at it on the small map, I see that there are actually quite a few flooding hazards. [P1]
- So first, I looked at the small map with the big overview. [P13]
- I nevertheless often looked at the [small] map and have actually thought at the beginning, [that I] do not need [it] at all, but have however consulted it quite frequently. [P18]

For 23.3% of the participants, the visualized buildings were also part of their strategy to estimate risk perception. Buildings were associated in both ways, either as an element that lowered risk perception or as a feature that increased the perceived risk.

- So, they are not in the least flow depth class… thus, these houses could cause damage. [P4]
- Because it has quite a few houses around, which means that this is certainly something that would block. [P14]

4.5.2 Group differences

This thesis mainly focuses on perception differences between 2D and 2.5D visualizations and thus, potential differences in strategies for assessing the risk perception between the groups will be also addressed in this subchapter. Eight strategies were identified and, as mentioned above, compiled in a frequency table. The frequency table with the division of the counts into 2D and 2.5D group is presented in Figure 45.

Frequency table of think-aloud transcripts

Statements related to...	2D	2.5D
specific flood depth at the house location	13	15
flood depths in the close surroundings	9	10
flood depths overlaps	10	6
infrastructure	4	3
topography	4	4
100 years return period	3	1
mentioning of visualization uncertainties	2	
consideration of the inset map	4	8

Figure 45: Strategy frequency table for the 2D and 2.5D group of the think-aloud transcripts

Strategies related to flood depth class at the house location and at its close surroundings were approximately equally mentioned in the 2D and 2.5D group. However, more participants of the 2D group (n = 10) mentioned that the house was located in several flood depth classes at once and this influenced their risk perception. In the 2.5D group, it seems that the existence of overlapping flood depth classes was not recognized by the participants as much as in the 2D group (n = 6). Another difference between the visualizations can be identified in the consultation of the inset map as a strategy. Participants viewing a 2.5D visualization seemed to consider the inset map more frequently (n = 8) than participants looking at a 2D visualization (n = 4). Topography as a reason for estimating the risk perception was equally mentioned in the 2D and 2.5D group (n = 4). This could be interpreted as surprising, since 2.5D visualization should ensure a lower cognitive effort for the participant to encode topographical information. However, the landscape of the city of Virginia Beach is relatively flat and this could be the reason why this advantage of 2.5D representations could not be observed.

In order to test whether the 2D and 2.5D group are independent from each other, a chi-square test of independence was conducted. The chi-square test showed no significant evidence that there is a relationship between the 2D and 2.5D group in mentioned strategies ($p = 0.6362 > 0.05$). Since the chi-square test can be inaccurate for smaller sample sizes, a Fisher's exact test for count data was conducted for comparative reasons. However, Fisher's exact test showed no significant difference between the groups in mentioned strategies ($p = 0.6514 > 0.05$).

Although no significant difference of mentioned strategies between the groups was found, the analysis of the think-aloud part revealed the following interesting points: Firstly, flood depth class overlaps were mentioned more by the participants that looked at 2D visualizations. Secondly, topography was equally considered in the 2D and 2.5D visualizations. Lastly, the inset map was taken more into account by participants that analyzed a 2.5D visualization.

5 Discussion

In this chapter, the three research questions will be discussed in terms of the obtained results. An attempt is made to connect my results to the existing literature regarding risk perception of flood risk visualization. At the end of this chapter, there is also a critical discussion of the methods used in the work and the results.

5.1 RQ1: Risk perception

With the first research question, I wanted to investigate how people rate their risk perception when viewing a 2D flood visualization compared to a 2.5D flood visualization. The hypothesis is that the participants assess the flood risk on a 2D visualization significantly lower than on a 2.5D visualization.

Participants that were given 2D flood visualizations rated their risk perception on average higher compared to participants who were shown 2.5D visualizations. Thus, it seems to be more likely that a participant who consults a 2D flood visualization perceives the flood hazard higher compared to its 2.5D equivalent. The statistical significance of the difference is rather ambiguous, as the significance level of $\alpha = 0.05$ is just fulfilled or not fulfilled depending on the choice of test (parametric or non-parametric).

Given that the 2.5D group included participants who, according to BART, were more willing to take risks (see Figure 40), it could also be possible that the visualizations alone are not the reason for the different risk ratings. However, it was shown in chapter 4.4.1 that the impact of the risk attitudes on the risk ratings is very small. Therefore, it can be assumed that the different risk ratings are not affected by individual's risk attributes. However, this still does not tell whether it can be assumed that the different risk ratings are only related to the visualizations. Demographic factors such as age, gender, level of education or previous knowledge can have an effect on risk perception (Kellens et al., 2011). Thus, a brief report on demographic differences was provided in the chapter 4.2.2. For instance, it can be recognized that especially in 2D visualizations female participants rated their risk perception higher than male participants did. This is consistent with the findings of Kellens et al. (2011) that, in general, females are more likely to rate risk higher in the context of natural hazard. It is also possible to see that participants with no university degree showed a bigger difference in risk ratings between 2D and 2.5D visualizations and a higher risk rating in general. I. Savage (1993) also found that people with a lower level of education show higher perceived risk levels. However, a very large difference across demographic groups cannot be detected in the mean error-bars of Figure 35. Because of the fact that the visualization between the groups only differ in dimensionality, it can be assumed that the difference in risk ratings is mainly a result of the change in dimensionality. Nevertheless, the difference between the risk ratings in the 2D flood visualizations and the 2.5D flood visualizations is statistically rather ambiguous with a significance level of $\alpha = 0.05$.

However, the academic literature also presents ambiguous results regarding comparative studies of 2D and 3D visualizations. For instance, Lieske et al. (2014) concluded that the use of web-based geovisualizations or 3D visualizations did not significantly differ in their influence on quantitatively measured risk perception. Nevertheless, there are also studies that imply a different risk perception with the change of dimensionality of a visualization. For instance, Evans et al. (2014) and Macchione et al. (2019) consider 3D visualizations as an appropriate visualization technique to raise risk awareness among the public. Especially Macchione et al. (2019) argue that a lack of historical photos which document a possible flood scenario can be compensated by realistic 3D visualizations. Those 3D visualizations present pictures that allow communicating the consequences of a flood in a less abstracted representation. Because of the lower abstraction, 3D visualizations are often perceived as closer to the real world and therefore 3D flooding scenarios are more threatening and can serve as "wake-up calls" (Evans et al., 2014). Surprisingly, the average risk ratings of the 2.5D flood visualizations were lower compared to the ones for the 2D flood visualizations in this study. Consequently, the threatening effect of flooding scenarios fostered by 3D visualizations cannot be proven in this study.

A possible reason why the threatening effect did not appear in the results of this study could manifest itself in the fact that the flood, with its various color-shaded depth classes, does not look as realistic as in the 3D visualizations of Evans et al. (2014) and Macchione et al. (2019). Thus, the influence of level of details in 2.5D visualizations on risk perception could be investigated in further research. Another possible reason why the risk ratings of the 2.5D visualizations are lower could be the visualized water level on the house facade, which is sometimes not visible at first glance. According to the literature, this water level represents an additional value of 2.5D or 3D visualizations compared to 2D visualizations because the consequences of the flood can directly be recognized in a less abstracted representation (Amirebrahimi et al., 2016; Leskens et al., 2017). In this study, the 3D water levels were made more transparent so that the discrete depth classes could still be visualized and ensure that similar color hues are used in both visualization types. However, the higher transparency resulted in a lower contrast between the house facade and the water and this sometimes required a closer look to see the water level more accurately. Nevertheless, the goal was to minimize the visual differences between the two visualization types so that potential differences in risk perception could be attributed to the change in dimension.

Thus, this thesis proposes the following answer to the first research question:

People rate their risk perception higher when viewing a 2D flood visualization compared to a 2.5D flood visualization. However, the statistical significance of this difference is ambiguous.

5.2 RQ2: Response time

With the second research question, I wanted to investigate what the drivers for potential differences in response time between 2D and 2.5D flood visualizations are. The hypothesis is that the participants need significantly more time to rate their risk perceptions on 2D flood visualizations than on 2.5D flood visualizations due to lower cognitive efforts in estimating the consequences of the flood.

In the study, participants that viewed 2.5D flood visualizations needed slightly more time to rate their risk perception compared to participants who were shown 2D flood visualizations. However, the significance of the difference in response times is not significant.

The existing literature confirms that people generally need more time and are less efficient to complete tasks that are solved using visualization with a third dimension. For instance, Popelka & Brychtova (2013) conducted a study to investigate potential differences in user cognition between 2D and 3D visualizations using eye-tracking metrics. “ScanPath length” was the only eye-tracking metric that differed between 2D and 3D visualization in the form of a longer scan path for 3D visualizations. A longer scan path indicates less efficient searching. Surprisingly, participants with previous knowledge in cartography had longer scan paths (Popelka & Brychtova, 2013). This coincides with the results of this study when looking at the demographic differences in chapter 4.3.2. There it can also be recognized that participants that indicated to be experienced in digital maps and flood maps needed for both, 2D and 3D flood visualizations, on average more time to respond than the inexperienced participants. This could be explained by the fact that participants who are experienced in using digital maps or flood maps might look at the maps in a more precise manner. It is also possible, however, that they considered themselves to be more experienced, they put even more effort into their answers. Nevertheless, this phenomenon could not be detected for participants with previous experiences in cartography and GIS.

A number of authors also pointed out that there are differences in response time between 2D and 3D visualization, depending on the type of tasks. D. M. Savage et al. (2004) concluded that for simple 2D tasks that do not require elevation data, participants were faster and more accurate in responding using 2D visualizations. However, for tasks that involved elevation data, the use of 3D visualizations resulted in a lower response time compared to 2D visualizations (D. M. Savage et al., 2004). This task dependency was also investigated by M. St. John, Cowen, Smallman, & Oonk (2001) with six types of tasks. For shape understanding and natural terrain tasks, a 3D perspective view delivered lower response times than the 2D views. However, the response time for relative positions tasks were lower for 2D views (M. St. John et al., 2001). The question of task dependency for rating risk perception on a flood visualization should, therefore, also be taken as a possible driver for the rather equal response times between the 2D and 2.5D flood visualization. According to the think aloud results provided in chapter 4.5, participants mainly focused on the flood depths right on or near the house locations. It can, therefore, be assumed that relative positioning strategies were applied when assessing the risks. At the same time, the flood visualizations also include elevation data. Many participants pointed out the possible topography and elevation of the water. In this study, the mixture of relative positioning tasks, where typically 2D visualizations are used to obtain faster responses, and elevation tasks, where people using 3D visualizations are typically faster, might have resulted in similar response times for both 2D and 2.5D flood visualizations.

Liao, Dong, Peng, & Liu (2017) reasoned differences in response times also depended on the type of task. In their study, Liao et al. (2017) investigated the influences of 3D geo-browsers on spatial knowledge acquisition and decision-making for navigation on pedestrian level. They stated that not only the task dependency (e.g. self-location, orientation tasks etc.) led to different response times but also the interactivity of the 3D geo-browser. Participants using the interactive 3D geo-browser had a significantly longer response time than the 2D participants (Liao et al., 2017). Liao et al. (2017) supposed that the extensively visual search of the participants using the 3D geo-browser resulted in a longer response time. The extensively visual search is most probably rooted in the information overload and object obstruction in the interactive 3D geo-browser (Liao et al., 2017). Wilkening & Fabrikant (2013) also attested a higher cognitive effort to the interactive 3D visualizations because of additional performance tools such as tilting and rotating. This study used static visualizations, so that the additional cognitive effort due to additional visual exploration and performance tools (tilting, rotation, zooming, panning) can be neglected. This might be another driver why the difference between the 2D and 2.5D flood visualization was extremely small. However, potential disadvantages of 3D visualizations such as symbol occlusion could lead to some additional cognitive effort, resulting probably in the slightly longer response time for 2.5D flood visualizations.

A minor driver for the slightly longer response time of participants that viewed 2.5D flood visualizations could be found in the more frequent consultation of the inset map. As mentioned in chapter 4.5, participants from the 2.5D group mentioned in the think aloud part twice as often that they had looked at the inset map. Assuming that the participants from the 2.5D group looked more at the inset map, it could be concluded that this was manifested in a longer response time due to additional interpretation.

In summary, the results of this study in terms of response times seem to be in line with those of the existing literature. The assessment of risk perception included both relative positioning tasks and height tasks, so no visualization type clearly produced smaller response times due to task dependence. Furthermore, the statistical visualization did not induce any further cognitive effort for 3D visualizations. The absence of these drivers can explain the quite similar response times between the 2D and 2.5D flood visualizations. A possible explanation for the very small difference in response times between the groups could be the more frequent consultation of the inset map by participants of the 2.5D group.

Thus, this thesis proposes the following answer to the second research question:

The participants needed slightly less time to assess their risk perception on a 2D than on a 2.5D visualization. However, the difference is very small and statistically not significant. This can be explained by the absence of a clear separation of 2D and 3D tasks as well as interactivity, which would probably have led to a higher visual exploration in the 2.5D group.

5.3 RQ3: Influence of risk attitude on risk perception

With the third research question, I wanted to investigate how people's individual attitudes towards risk affect their risk perception. The hypothesis is that the more risk-seeking a participant is, the lower are his or her risk ratings based on the flood visualizations.

A multiple linear regression model (Table 8) and a linear mixed-effect model (Table 9) revealed that the influence of individual risk attitudes on participants' risk ratings is very weak. A quite large change in the scores of the risk attitude test measure BART leads to only a very small decreasing change in average risk ratings. Thus, people's individual attitudes towards risk do not influence their average risk ratings.

The results that risk attitude has such a small influence on risk perception was surprising. In theory, risk perception is negatively correlated with risk-taking behavior (Mills, Reyna, & Estrada, 2008). In other words, the higher the risk of a behavior is perceived, the lower the chance to engage in that behavior (Mills et al., 2008). However, there are also studies that observed a positive correlation between risk perception and risk-taking behavior. For instance, Johnson, McCaul, & Klein (2002) discovered that smokers perceived smoking as riskier than nonsmokers did. This describes the relationship that the higher the perceived risk for a behavior, the higher is the chance to engage in that behavior. For this study, these opposite relations may be a reason that no correlation between individual's risk attitude and risk perception has emerged. BART as a risk measure involves actually risky behavior (Lejuez et al., 2002). And as mentioned before, one would suggest intuitively that a high point score in the BART (identifies a risk-seeking participant) might lead to lower risk perception ratings in the visualization tasks, since a risk-seeking participant would rather build a house in a hazard zone than a risk-averse participant (with a low BART score). But as Johnson et al., (2002) pointed out, this relationship does not necessarily always have to be negatively correlated. Consequently, a rather risk-averse participant (with a low BART score) might perceive a house location as similar as or even less risky than a risk-seeking participant (with a high BART score).

Another reason for the weak influence of individual's risk attitudes might be found in the type of the tasks of this study. As illustrated in Figure 20, a possible loss is weighted more than a possible gain for a risk-averse person. Thus, a risk-averse person chooses the safest win although the win could be higher (Kahneman & Tversky, 1979). While there is a possible gain in the BART in the form of virtual money and a possible loss when the balloon popped, rating risk does not present itself as a typical gain and loss task. Since there are no right and wrong answers in the visualization tasks, participants cannot win or lose anything like in the BART. In addition, it is quite difficult and expensive to build a house in Switzerland and this might be a reason why probably some participants have not perceived it as a realistic scenario. The different task types of the BART and visualization tasks and the fact that some participants might have thought that they would never be in such a scenario, could have influenced the relationship between risk attitude and risk perception.

Understanding risk perception with the help of multiple regression analysis is quite widespread in the literature. To create a powerful model, demographics are often taken into account. For instance,

I. Savage (1993) used regressions to connect demographic characteristics of participants to hazard risk perceptions. The results showed that especially women, people with a lower level of income and education, blacks and younger people are more afraid of hazards (I. Savage, 1993). Kellens et al. (2011) investigated the public perception of flood risk with various measured personal and residence characteristics. They noticed that age, gender, experience with previous flood hazards and flood risk estimates were the primary predictors of risk perception (Kellens et al., 2011). Thus, the rather low value of the regression model for this study can be explained by missing demographic predictors. However, the intention of this third research question was not to explain as much of the variance as possible, but rather to investigate the influence of risk attitude on risk perception.

Nevertheless, a small exploration of the demographic influence on the relationship between risk attitude and risk perception was conducted. Both gender and experience in using maps did not significantly influence this relationship. However, it was observed in Figure 44 that the relationship between risk attitude and risk perception moved from very slightly negative correlation to no correlation at all when experience in using maps was included. This could imply that participants with experience in using maps read and interpret them differently and therefore, reduce the effect of risk attitude on risk perception.

This thesis proposes the following answer to the third research question:

The relationship of the measured risk attitude on risk perception shows a very weak and slightly negative correlation. Thus, the influence of risk attitude on risk perception is not statistically significant. This can be explained by the still debated relation between risk perception and risk-taking behavior and the absence of clear gains and losses in the risk perception tasks.

5.4 Think aloud

With the think aloud method, participants' strategies for rating their risk perception were identified. This obtained qualitative data allows deepening the knowledge of the quantitative data evaluated for the three research questions.

A quantitative content analysis revealed that on the one hand the participants from the 2.5D group looked at the inset map more frequently than participants from the 2D group. On the other hand, the participants from the 2D group mentioned the overlaps of the flood depth classes more often. Overall, a chi-squared test showed no significant difference between the mentioned strategies of the participants in the 2D and 2.5D group.

In both groups, both inset maps were shown in 2D. A possible explanation for the more frequent consultation of the map in the 2.5D group could therefore be that a rough overview is created more quickly with a small-scaled orthogonal 2D map than a bigger scaled 2.5D oblique view. As shown in Figure 45, closeness to deeper flood depth classes was mentioned with equal frequency between the 2D and 2.5D groups, and a rough overview was needed to identify these closer flood depth classes. For interpreting relative positions, an orthogonal 2D map is easier to read than 3D oblique views (St. John et al., 2000). This could be a possible reason why participants from the 2.5D group mentioned the inset map more frequently than participants from the 2D group in the think-aloud part.

The visualizations followed a systematic trial distribution in terms of complexity. In one group, four visualizations showed the house location in one flood depth class, eight visualizations in two flood depth classes and another four visualizations in three different flood depth classes (see appendix D). However, these overlaps were more frequently mentioned by participants in the 2D group (n=10) than by participants in the 2.5D group (n=6). A possible reason for that could be rooted in symbol occlusion, a mentioned disadvantage of static 3D visualizations (see chapter 2.3.2). Symbol occlusion describes the phenomenon that smaller objects in the background are hidden by larger objects in the foreground depending on the user's viewpoint (Niedomysl et al., 2013). In the 2.5D flood visualization, the house markers were also visualized in 2.5D and in combination with the oblique view, it can sometimes be difficult to imagine the overlaps "behind" the marker. However, attention has been paid to prevent this as much as possible, but with a static 3D visualization, preventing symbol occlusion can never be completely guaranteed. Possible solutions to avoid symbol occlusion is to avoid static 3D visualizations and rather provide interactive 3D visualizations. In this case, people could move their viewpoint and bypass the occlusion problems (Shepherd, 2008). However, this finding might indicate that the risk perception in some static 2D and 2.5D visualizations is not only rated slightly differently, but also explains why it is rated differently. As further research, an eye-tracking study would provide even more detailed information on differences in visual strategy between 2D and 2.5D visualizations.

Finally, the think-aloud was also very useful to verify that the participants understood the task correctly and that there were no misunderstandings. For instance, Lieske et al. (2014) mentioned that the additional cognitive effort to imagine the real world in a 2D and 2.5D abstraction can lead to misunderstandings. The think-aloud test ensured that only data from participants who had understood the task correctly were examined in the analysis.

5.5 Study reflection

In the following, I would like to critically reflect on the methodology used, which should be taken into account when interpreting the results.

As mentioned in chapter 3.1, not all participants had the same room conditions while they completed the study. Due to the COVID-19 situation, I decided to visit participants so that they could conduct the study without leaving their home. On the one hand, a disadvantage of this method is that not all environmental or room conditions respectively could be controlled. Thus, circumstances such as different sounds and lights could have influenced the results. Nevertheless, the same hardware and same display brightness was used for every participant in order to control at least some variables. On the other hand, the varying study places increase the representativeness of the study since no artificial environments were used (Martin, 2008).

Regarding the study design, it is important to note that while the between-subject design ensures that one visualization type does not affect the other visualization type, it cannot guarantee that the two groups of participants are considered equivalent to each other (Martin, 2008). Especially because of the rather small sample size of 15 participants in each group, the results should always be interpreted carefully.

It can also be questioned whether the task was realistic with the different house locations. Especially in Switzerland, buying land and building a house is very expensive and it is very likely that not all participants will want to buy a house in the future. Therefore, the identification of the participants with the task can be questioned. However, with the scenario of buying one's own house, the study wanted to bring the visualization tasks to a personal level as far as possible

A limitation could also be that most of the participants in the 2.5D group did not pay attention to the water level on the house facade. At least this was never mentioned in the think-aloud part. Indeed, the 3D water levels were more difficult to see at first glance due to the transparency settings. Since flooding is a volumetric phenomenon, water levels on the house facade are a big advantage of the 2.5D visualization compared to the 2D visualization (Amirebrahimi et al., 2016; Zhi et al., 2020).

Another limitation regarding the generation of the visualization is the angle setting of the 2.5D visualizations. In ArcGIS Pro, the angle could not be entered with a manual value, so I set it manually by hand with the navigator. However, for the height above the ground, a value could be entered manually. Before exporting the 2.5D visualizations, I made sure that they all had the same height above ground and the same angle according to the navigator. Nevertheless, this uncertainty must be taken into account.

6 Conclusion and outlook

6.1 Conclusion

The importance of precise information to prevent people from damage is shown by the increasing frequency of flood events around the world (Hagemeier-Klose & Wagner, 2009). As a result, various frameworks and measures have been created by authorities to take preventive measures against the risk of flooding. However, the success of these measures in raising the population's awareness of flood risk is rather moderate. For instance, Rollason et al. (2018) pointed out that only 45% of people in the UK who are living in risk areas are aware of the risk. Current 2D flood maps seem not to fulfill the task of raising risk awareness among the public because people have difficulties in interpreting a cartographic abstraction of the real world (Haynes et al., 2007). However, technological progress allows new possibilities to visualize flood risk. In particular, 3D visualizations are undergoing a trend and are gradually discussed in the scientific literature (Macchione et al., 2019). Visualizations play an important role in people’s risk perception (Lieske et al., 2014), but the existing research is rather undecided whether 2D or 3D visualizations are more appropriate in terms of overall usefulness (Niedomysl et al., 2013).

Existing literature mainly measured overall usefulness with user’s preferences and accuracy of risk communication (Franz et al., 2015). In existing comparative studies between 2D and 3D visualizations, the effect of the change in dimension on the perception of flood risk is mostly not considered. The overall aim of this thesis is to address this research gap by investigating how different visualization types affect our flood risk perception. In more detail, this thesis investigates three questions. Firstly, how do people rate their risk perception when viewing a 2D flood visualization compared to a 2.5D flood visualization? Secondly, what are the drivers for potential differences in response time between a 2D and a 2.5D flood visualization? Thirdly, how do people’s individual risk attitudes affect their risk perception?

In order to answer the three research questions, an experimental study with 30 participants was conducted. The participants analyzed either at 16 2D or 16 2.5D flood visualization with one house marker per visualization that indicated a possible location for building their own house. For each of the 16 visualizations, participants were asked how risky they thought it would be to build their house at the location of the house marker. They were asked to rate the risk on a 7-point scale from “minimum” to “maximum”. Statistical methods were then used to investigate the three research questions.

For the first research question, I hypothesized that people that viewed a 2D flood visualization rate their risk perception lower than people that viewed at a 2.5D flood visualization. Based on the results, this hypothesis cannot be confirmed. The participants who had viewed at 2.5D visualizations rated their risk perception lower than the participants who had viewed at 2D visualizations. However, academic research is also rather ambiguous when it comes to comparative studies on the use of 2D and 3D visualization and their effect on people (Popelka & Brychtova, 2013; D. M. Savage et al., 2004; Schobesberger & Patterson, 2008; M. St. John et al., 2001).

For the second research question, I hypothesized that people need more time to rate their risk perceptions with a 2D flood visualization than with a 2.5D flood visualization because of a larger cognitive effort in the 2D abstraction. Based on the results, this hypothesis cannot be confirmed. There is rather a tendency that the participants with 2.5D visualizations took longer to rate their risk perception. However, the difference is very small, which could be because there are hardly any visual differences between the two visualizations, except for the change in dimension.

For the third research question, I hypothesized that risk-seeking people rate their risk perception lower than risk-averse people do and thus, individual's risk attitude has an influence on risk perception ratings. Based on the results, this hypothesis cannot be confirmed. There is a very weak and slightly negative correlation between risk attitudes and risk ratings. However, this correlation is so small that it can be neglected. Therefore, no influence of individual risk attitudes on risk ratings could be observed. One reason could be that the risk measure BART and the risk perception tasks differed in terms of the loss and gain principle. While there were points to be gained in the BART, risk ratings do not directly test risk behavior because there is no direct loss or gain. This may have been a reason for the very weak correlation between risk attitude and risk ratings.

According to this study, 3D visualizations are not necessarily needed to make people aware of flood risk. However, the 2.5D flood visualizations of this work had a relatively low level of detail. It could be that a higher level of detail has an additional influence on the risk perception. However, the aim of this thesis was to find out whether the change in dimension alone has an influence on our risk perception. No significant influence was found, but the participants rated the 2D visualizations with a slightly higher average risk.

Understanding the determining factors of people's risk perception is essential for improving risk communication (Kellens et al., 2011). The answers of this thesis' research questions help to promote this understanding by illustrating the influence of changing dimensions in flood visualizations on people's risk perception.

6.2 Outlook

There are several other research gaps in the area of the influence of visualization types on flood risk perception. In this subchapter, I will first mention possible future research based on the present thesis and, in a second step, address general research directions within this field.

Some researchers identified previous flood experiences as one of the most determining factor of risk perception (Bradford et al., 2012; Kellens et al., 2011; Wachinger et al., 2013). In a further study, it would be interesting to observe how flood visualizations interact with people's previous flood experiences as determinants of risk perceptions.

As already indicated in the previous subchapter, it would be very interesting to investigate how an increasing level of detail in 3D visualization affects our risk perception. Similar research has been done, for example, by Rahel Klausener with respect to the acceptance of construction projects (Klausener, 2012). In this work, only a low level of detail was chosen so that possible differences in the risk perception of the participants could be attributed as far as possible only to the added dimension.

It would be interesting for a further study to include additional information such as house price and the losses as a result of damage as Kübler (2016) did in her master thesis. Then, the rating of the risk perception would be based on additional factors that convey a feeling of gain and loss. It would be interesting to see if the relationship between the risk ratings with additional factors and the BART would be different thereafter.

In this study, the think-aloud method was chosen so that participants' strategies for rating their risk perception could be understood. As another possibility, the eye-tracking method could also be considered in the future. This would probably allow to better investigate potential differences in visual strategies between visualizations and avoid the uncertainty that not all participants shared the same amount of thoughts in the think-aloud.

A limitation of this study was that the 3D water was not clearly identifiable on the house facades in the 2.5D visualization due to its transparency settings. In the future, this limitation could be avoided by displaying the flood depth raster, which is projected on the ground, continuously instead of discretely. Furthermore, the 3D water could be displayed with different transparency values depending on its depth. This would lead to an intuitive understanding of depth and possibly achieve the threatening effect of 3D visualization as described by Evans et al. (2014) and Macchione et al. (2019). Therefore, it would be interesting to see if a continuous representation of flood depth has a different impact on our risk perception than a discrete classification.

Finally, the focus should not only be on static 2D and 2.5D visualizations. The mentioned progress of technology allows many possibilities to compare different types of visualization and their impact on our risk perception. For instance, augmented reality and virtual reality applications could also be considered.

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Appendix

A. Meta data of the flood depth raster dataset


```
- <detailed>
  - <enttyp>
      <enttypl>CstDpth_01pct</enttypl>
      <enttypd>Raster dataset of flood depth for a coastal 1% event.</enttypd>
      <enttypds>FEMA Flood Risk Database Technical Reference (available at http://www.fema.gov/media-library/assets/documents/32348?id=7414 and on the FEMA Risk MAP
        Knowledge Sharing Site)</enttypds>
    </enttyp>
  </detailed>
```

B. Consent form for the study

Universität Zürich – **Einwilligungsformular** Masterarbeit: Risiko-Wahrnehmung bei Überflutungskarten
Teilnehmernummer:

Zweck der Studie

Du bist eingeladen, an einer Studie zur «Risikowahrnehmung bei Überflutungskarten» teilzunehmen. Wir möchten mit dieser Studie neue Erkenntnisse über die Wahrnehmung von Risiken mithilfe einer Überflutungskarte und den damit verbundenen kognitiven Prozessen gewinnen. Dieses Experiment wird von Fabian Kuster im Rahmen seiner Masterarbeit durchgeführt. Die Masterarbeit wird von Prof. Dr. Sara Fabrikant und Dr. Ian-Tanner Ruginski am Geographischen Institut der Universität Zürich geleitet.

Ablauf der Studie

Falls du dich entscheidest an der Studie teilzunehmen, wirst du zuerst gebeten einen Fragebogen mit einigen Angaben zu deiner Person auszufüllen. Danach wirst du ein kleines Spiel durchzuführen. Im Hauptteil wirst du gebeten, mithilfe von Überflutungskarten das Risiko an verschiedenen Standorten zu beurteilen. Genauere Erklärungen werden während dem Experiment gegeben. Nach dem Experiment wird es einen kurzen Abschlussteil geben, wo du deine Vorgehensweise sprechend dokumentieren wirst. Dies wird mit dem Smartphone aufgezeichnet. Es werden insgesamt folgende Daten anonymisiert registriert: Angaben zum Fragebogen am Anfang, Antworten beim kleinem Spiel, Antworten und die benötigte Antwortzeit bei der Risikobeurteilung während des Hauptexperiments. Die Audio-Datei auf dem Smartphone zum „lauten Denken“ wird nach der Transkription gelöscht. Der Versuch findet in Sursee in einem Büroraum statt. Er dauert ungefähr 30 Minuten und beinhaltet keinerlei Risiken für dich.

Vertraulichkeit der Daten

Jegliche Informationen, welche während der Studie mit dir in Verbindung gebracht werden können, werden vertraulich behandelt und nur mit deiner ausdrücklichen Erlaubnis an Dritte weitergegeben. Mit deiner Unterschrift erlaubst du uns, die anonymisierten Ergebnisse des Versuchs mehrmals zu publizieren. Dabei werden keinerlei Informationen veröffentlicht, die es ermöglichen, dich zu identifizieren.

Bekanntgabe der Ergebnisse

Wenn du dich über die Ergebnisse der Studie auf dem Laufenden gehalten werden möchtest, bitten wir dich, dem Versuchsleiter oder der Versuchsleiterin deine Anschrift zu hinterlassen. Eine Kopie von zukünftigen Publikation(en) wird dir daraufhin zugestellt.

Einwilligung

Deine Entscheidung, an der Studie teilzunehmen oder nicht, wird zukünftige Beziehungen mit der Universität Zürich nicht beeinträchtigen. Entscheidest du dich dafür, an der Studie teilzunehmen, steht es dir jederzeit frei, die Teilnahme ohne Begründung abzubrechen. Solltest du Fragen haben, zögere bitte nicht, uns diese zu stellen. Sollten zu einem späteren Zeitpunkt Fragen aufkommen, wird Fabian Kuster (078 792 05 16, fabian_kuster@hispeed.ch) oder Prof. Dr. Sara I. Fabrikant (sara@geo.uzh.ch), diese gerne beantworten. Du erhälst eine Kopie dieses Dokuments.

Mit deiner Unterschrift bestätigst du, oben stehende Informationen gelesen und verstanden zu haben und willigst ein, unter den dort beschriebenen Bedingungen am Experiment teilzunehmen.

Unterschrift des Teilnehmers | Unterschrift des Experimentleiters

Vor- und Nachname in Blockschrift | Vor- und Nachname in Blockschrift

Ort / Datum

Universität Zürich – Einwilligungsformular Masterarbeit: Risiko-Wahrnehmung bei Überflutungskarten

Widerruf der Einwilligung

Hiermit möchte ich meine Einwilligung, an der oben beschriebenen Studie teilzunehmen, widerrufen.

Unterschrift | Vor- und Nachname in Blockschrift

Ort / Datum

Mit dem Widerruf der Einwilligung beeinträchtigst du in keiner Weise deine Beziehungen mit der Universität Zürich. Der Widerruf kann jederzeit und ohne Angabe von Gründen beantragt werden. Den Widerruf der Einwilligung bitte an Prof Dr. Sara I. Fabrikant, Geographische Informationsvisualisierung und Analyse, Geographisches Institut, Universität Zürich, Winterthurerstr. 190, 8057 Zürich senden.

C. Pretest: personal questionnaire

1 **ID:**

#

2 **Geschlecht:**

- ◯ Weiblich
- ◯ Männlich

3 **Alter?**

#

4 **Wurde dir von einer Fachperson (Augenarzt, Optiker) mitgeteilt, dass du von einer Rot-Grün-Sehschwäche oder Farbenblindheit betroffen bist?**

- ◯ Ja, Rot-Grün-Sehschwäche
- ◯ Ja, Farbenblindheit
- ◯ Nein

5 **Was ist deine höchste abgeschlossene Ausbildung?**

- ◯ Kein Abschluss
- ◯ Obligatorische Grundschule
- ◯ Berufslehre
- ◯ Maturität
- ◯ Höhere Berufsbildung
- ◯ Uni, Hochschule

6 **Wie häufig gehst du Freizeitaktivitäten nach, die den Gebrauch von Karten erfordern (z.B. Wandern, Fahrradfahren, Skitouren, Segeln, Städtetrip etc.)?**

- ◯ Nie
- ◯ Selten (höchstens einmal im Monat)
- ◯ Manchmal (zwei bis dreimal im Monat)
- ◯ Oft (einmal pro Woche)
- ◯ Sehr oft (mehrmals pro Woche)

7 **Wie gross ist deine Erfahrung in folgenden Bereichen? (1 = noch nie gehört, 2 = schon mal gesehen bzw. davon gehört, 3 = ein- bis zweimal bereits etwas mithilfe dieses Bereiches bearbeitet, 4 = Viel Erfahrung in diesem Bereich, 5 = täglicher Gebrauch)**

	1	2	3	4	5
Kartographie	○	○	○	○	○
Geographische Informationssysteme (GIS)	○	○	○	○	○
Digitale Karten	○	○	○	○	○
Überflutungskarten	○	○	○	○	○

D. Trial distribution for the main study

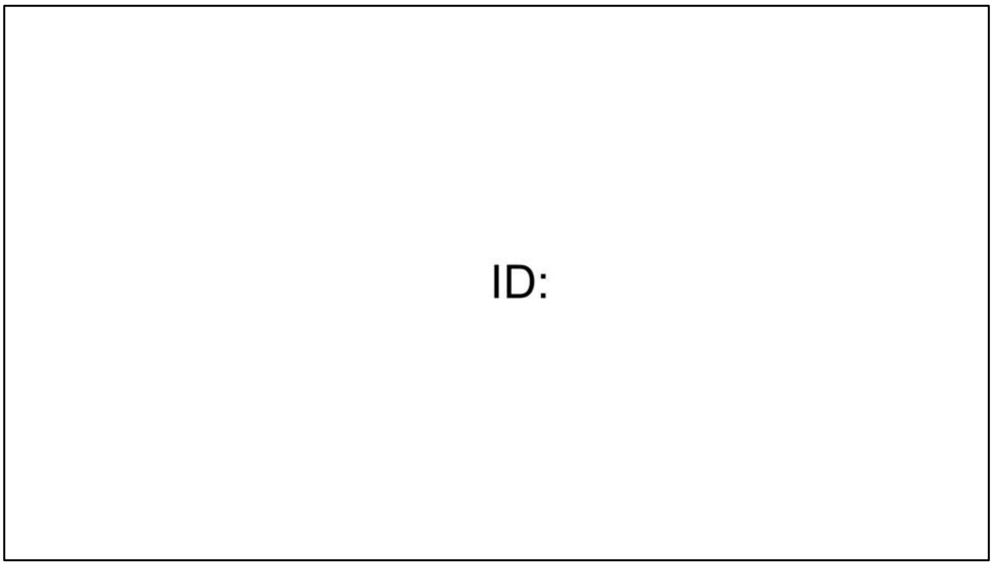
Classification	Number of overlapping flood-depths by building	Average level of flood-depth in meters	Visualization
Easy	1	0	K1/K2
Easy	1	0.1-0.5	J1/J2
Easy	1	1.1-1.5	G1/G2*
Easy	1	1.6-2.0	E1/E2

Classification	Number of overlapping flood-depths by building	Average level of flood-depth in meters	Visualization
Medium	2	0 | 0.1-0.5	P1/P2
Medium	2	0.1-0.5 | 0.6-1.0	M1/M2
Medium	2	0.1-0.5 | 0.6-1.0	F1/F2*
Medium	2	0.1-0.5 | 0.6-1.0	D1/D2
Medium	2	0.6-1.0 | 1.1-1.5	L1/L2
Medium	2	0.6-1.0 | 1.1-1.5	A1/A2
Medium	2	0.6-1.0 | 1.1-1.5	N1/N2
Medium	2	1.1-1.5 | 1.6-2.0	O1/O2

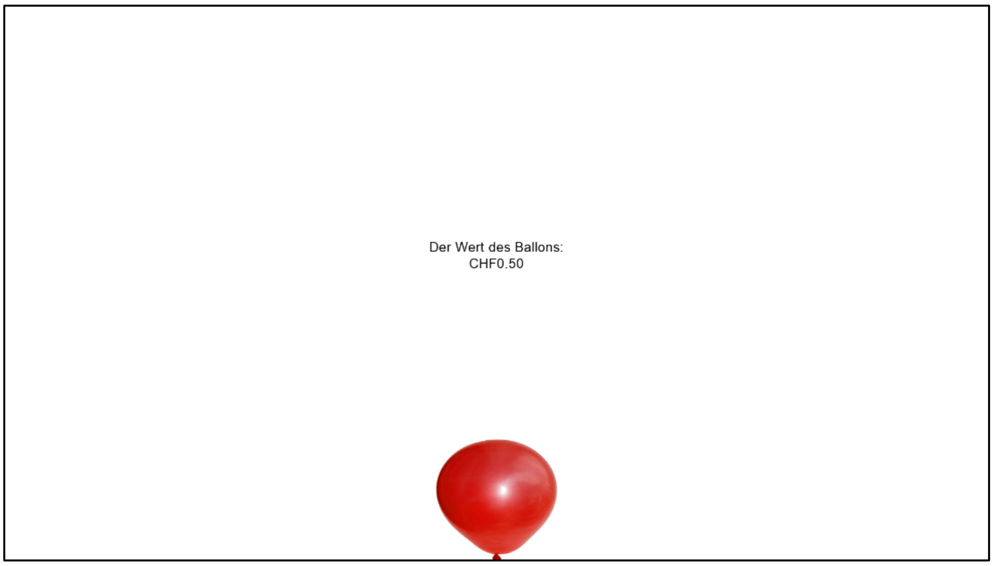
Classification	Number of overlapping flood-depths by building	Average level of flood-depth in meters	Visualization
Hard	3	0 | 0.1-0.5 | 0.6-1.0	B1/B2
Hard	3	0.1-0.5 | 0.6-1.0 | 1.1-1.5	C1/C2*
Hard	3	0.1-0.5 | 0.6-1.0 | 1.1-1.5	I1/I2
Hard	3	0.6-1.0 | 1.1-1.5 | 1.6-2.0	H1/H2

* Used in Think aloud session

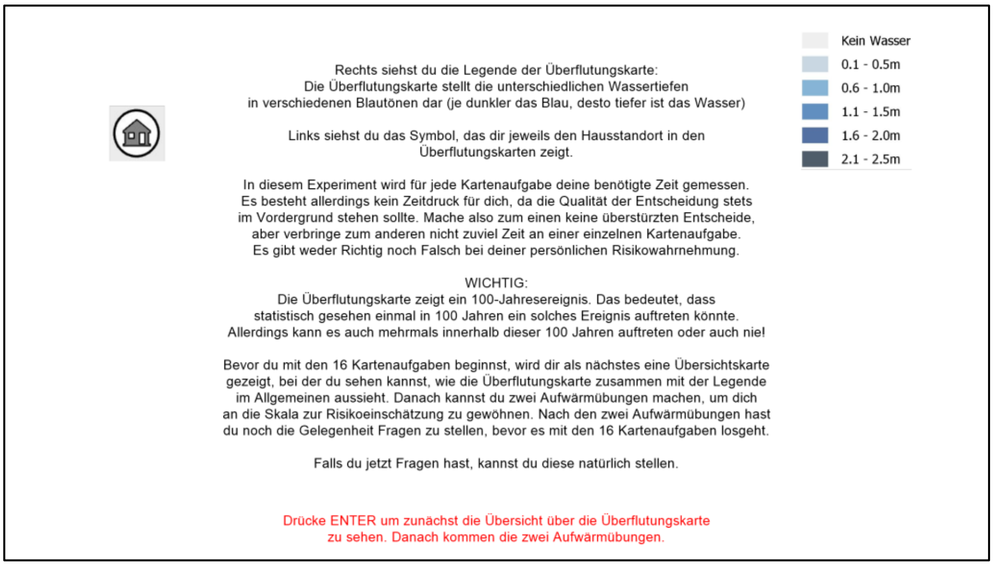
E. Example scenario for the 2D group



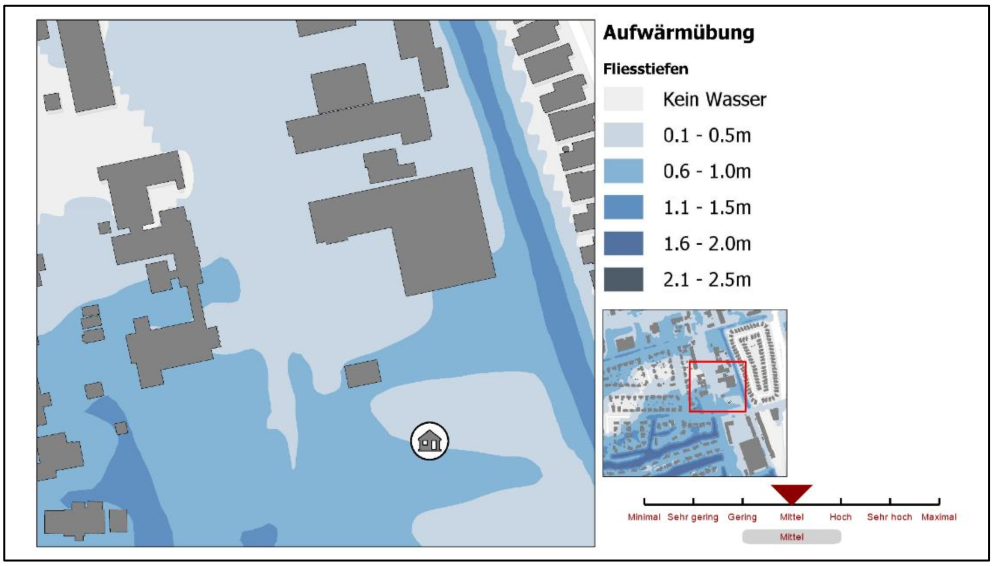

Der Wert des Ballons:
CHF0.00

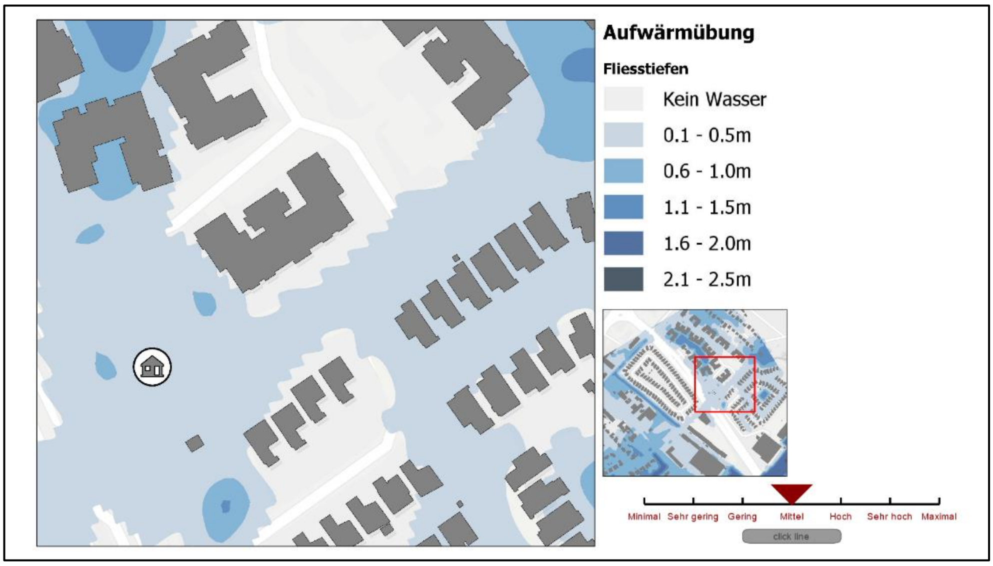

Der Wert des Ballons:
CHF0.50


Stell dir vor du möchtest ein Haus bauen und hast bereits eine erste Vorauswahl für mögliche Standorte getroffen. Einen genauen Entscheid, wo du dein Haus bauen möchtest, konntest du aber noch nicht fällen. Da du dein zukünftiges Haus möglichst vor Überschwemmungen schützen möchtest, schaust du dir nun auch die Überflutungskarte an.
Mit der Überflutungskarte willst du herausfinden wie stark dein zukünftiges Haus dem Risiko einer möglichen Überflutung ausgesetzt ist.
Du hast insgesamt 16 Standorte gefunden, die für einen Hausbau in Frage kommen.
Deine Aufgabe ist es nun das Überflutungsrisiko für jeden dieser Haus-Standorte auf einer Skala von 1 bis 7 abzuschätzen (entspricht 16 Kartenaufgaben).
Du solltest dir also bei jeder der 16 Kartenaufgaben die folgende Frage stellen:
Wie riskant ist es, bezogen auf das Überflutungsrisiko, an diesem Standort ein Haus zu bauen?
Minimal
Sehr gering
Gering
Mittel
Hoch
Sehr hoch
Maximal
click line
Auf der Skala klickst du mit der Maus auf den gewünschten Wert und klickst danach wieder mit der Maus in das graue Kästchen unterhalb der Skala.
Drücke ENTER um weitere Infos zu erhalten.


Kein Wasser
0.1 - 0.5m
0.6 - 1.0m
1.1 - 1.5m
1.6 - 2.0m
2.1 - 2.5m
Rechts siehst du die Legende der Überflutungskarte:
Die Überflutungskarte stellt die unterschiedlichen Wassertiefen
in verschiedenen Blautönen dar (je dunkler das Blau, desto tiefer ist das Wasser)
Links siehst du das Symbol, das dir jeweils den Hausstandort in den
Überflutungskarten zeigt.
In diesem Experiment wird für jede Kartenaufgabe deine benötigte Zeit gemessen.
Es besteht allerdings kein Zeitdruck für dich, da die Qualität der Entscheidung stets
im Vordergrund stehen sollte. Mache also zum einen keine überstürzten Entscheide,
aber verbringe zum anderen nicht zuviel Zeit an einer einzelnen Kartenaufgabe.
Es gibt weder Richtig noch Falsch bei deiner persönlichen Risikowahrnehmung.
WICHTIG:
Die Überflutungskarte zeigt ein 100-Jahresereignis. Das bedeutet, dass
statistisch gesehen einmal in 100 Jahren ein solches Ereignis auftreten könnte.
Allerdings kann es auch mehrmals innerhalb dieser 100 Jahren auftreten oder auch nie!
Bevor du mit den 16 Kartenaufgaben beginnst, wird dir als nächstes eine Übersichtskarte
gezeigt, bei der du sehen kannst, wie die Überflutungskarte zusammen mit der Legende
im Allgemeinen aussieht. Danach kannst du zwei Aufwärmübungen machen, um dich
an die Skala zur Risikoeinschätzung zu gewöhnen. Nach den zwei Aufwärmübungen hast
du noch die Gelegenheit Fragen zu stellen, bevor es mit den 16 Kartenaufgaben losgeht.
Falls du jetzt Fragen hast, kannst du diese natürlich stellen.
Drücke ENTER um zunächst die Übersicht über die Überflutungskarte
zu sehen. Danach kommen die zwei Aufwärmübungen.


Fliesstiefen
Kein Wasser
0.1 - 0.5m
0.6 - 1.0m
1.1 - 1.5m
1.6 - 2.0m
2.1 - 2.5m


Aufwärmübung
Fliesstiefen
Kein Wasser
0.1 - 0.5m
0.6 - 1.0m
1.1 - 1.5m
1.6 - 2.0m
2.1 - 2.5m
Minimal
Sehr gering
Gering
Mittel
Hoch
Sehr hoch
Maximal
Mittel


Aufwärmübung
Fliesstiefen
Kein Wasser
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0.6 - 1.0m
1.1 - 1.5m
1.6 - 2.0m
2.1 - 2.5m
Minimal
Sehr gering
Gering
Mittel
Hoch
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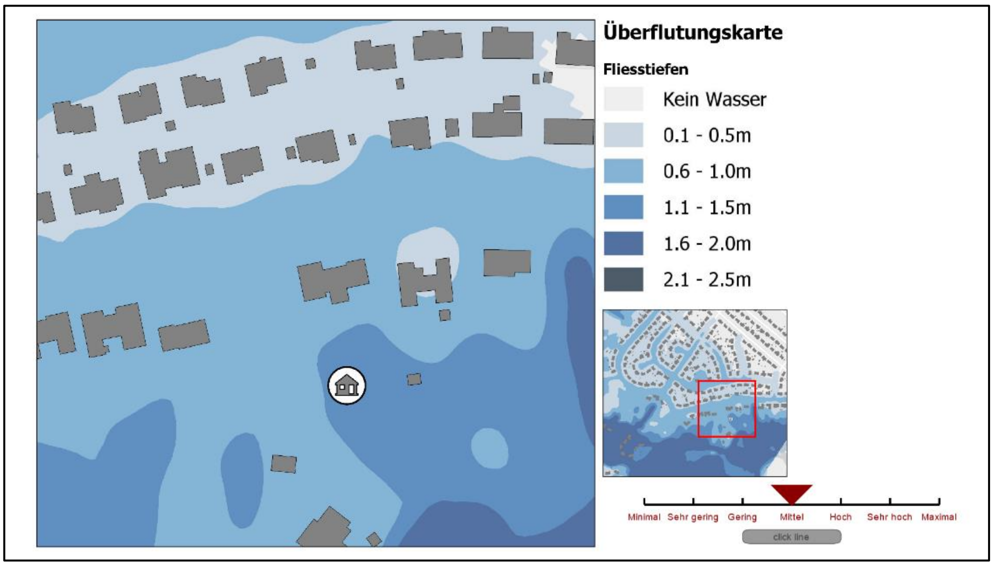
Start
Hast du noch Fragen?
Sobald du ENTER drückst, wird das Experiment starten


Überflutungskarte
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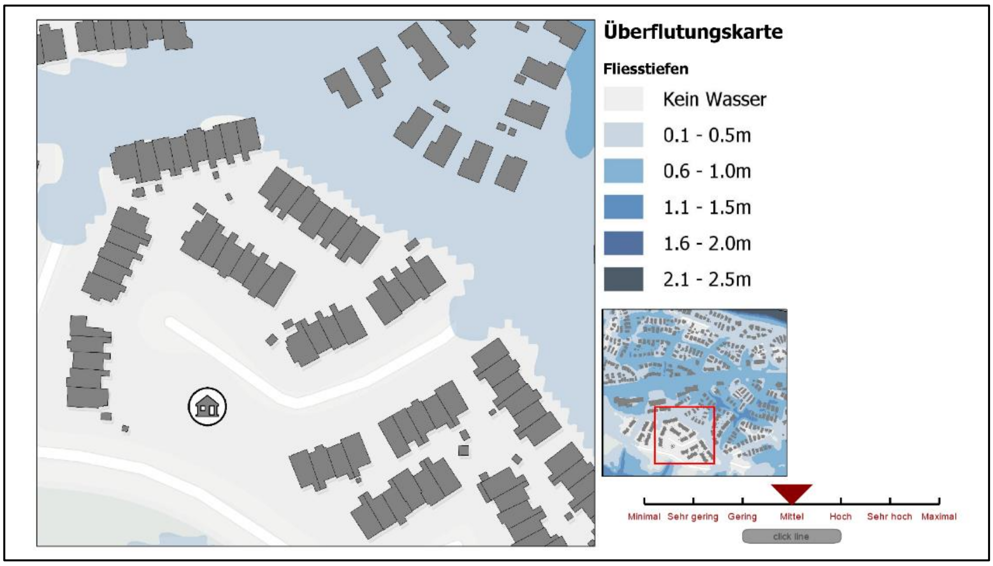
Überflutungskarte
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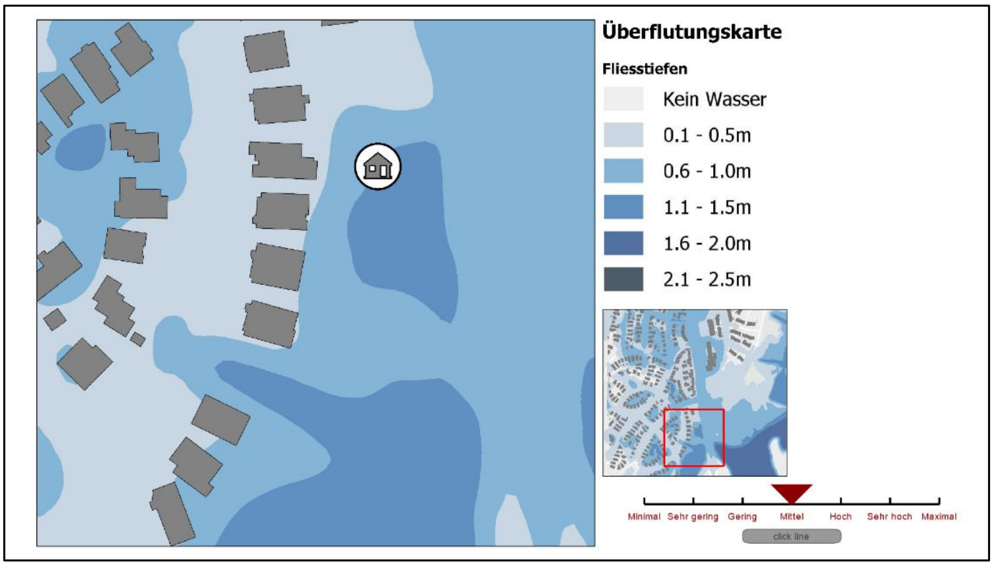
Überflutungskarte
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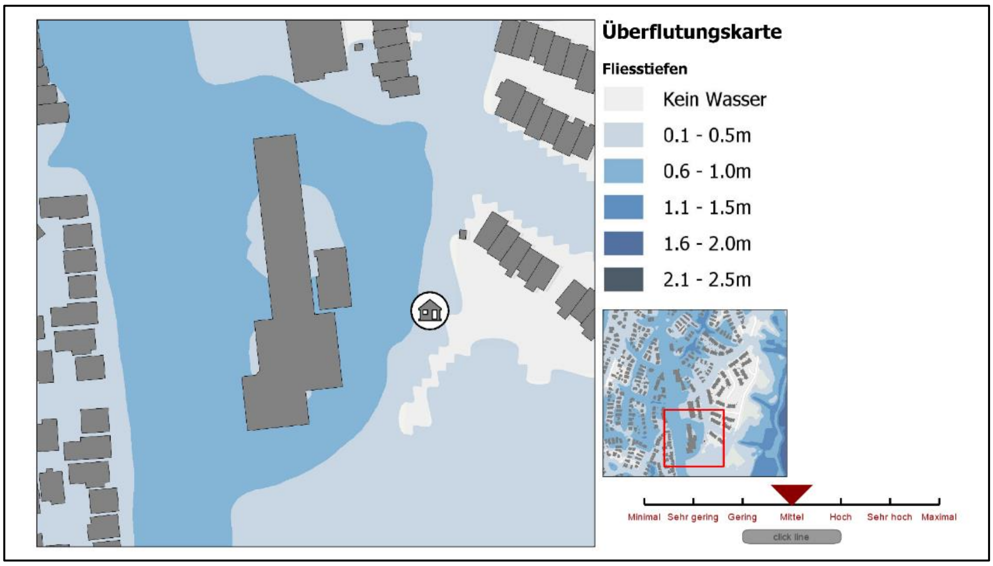
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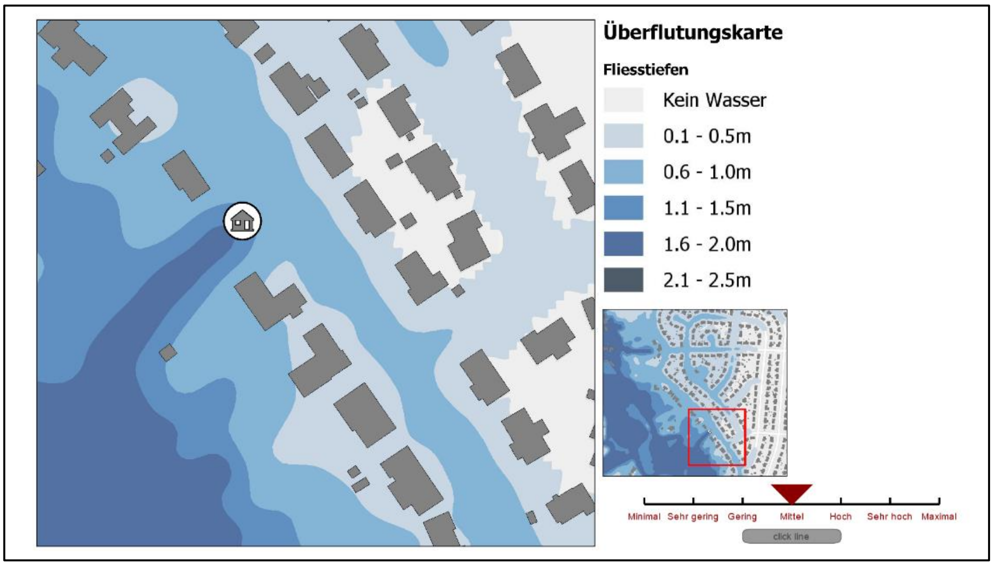
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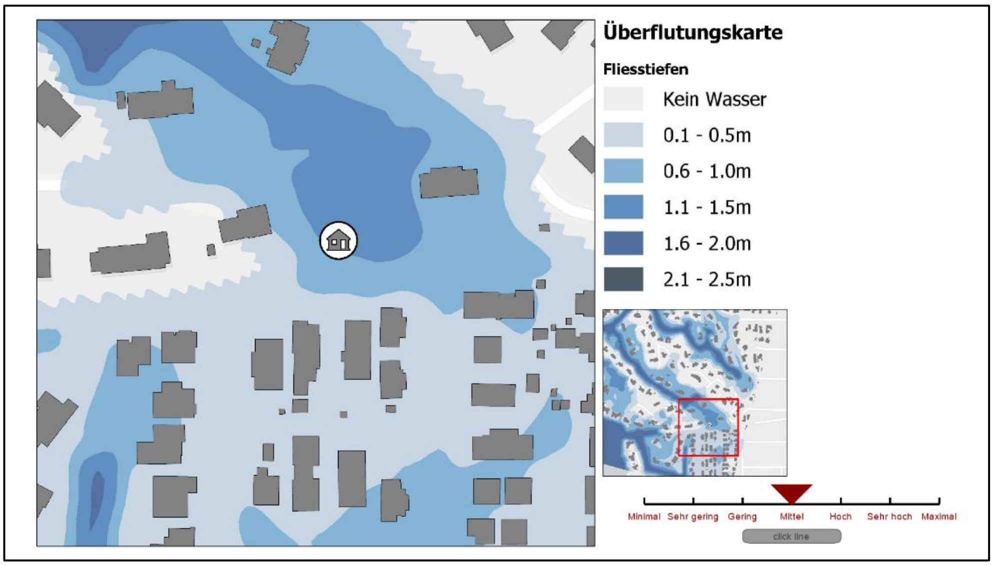
Überflutungskarte
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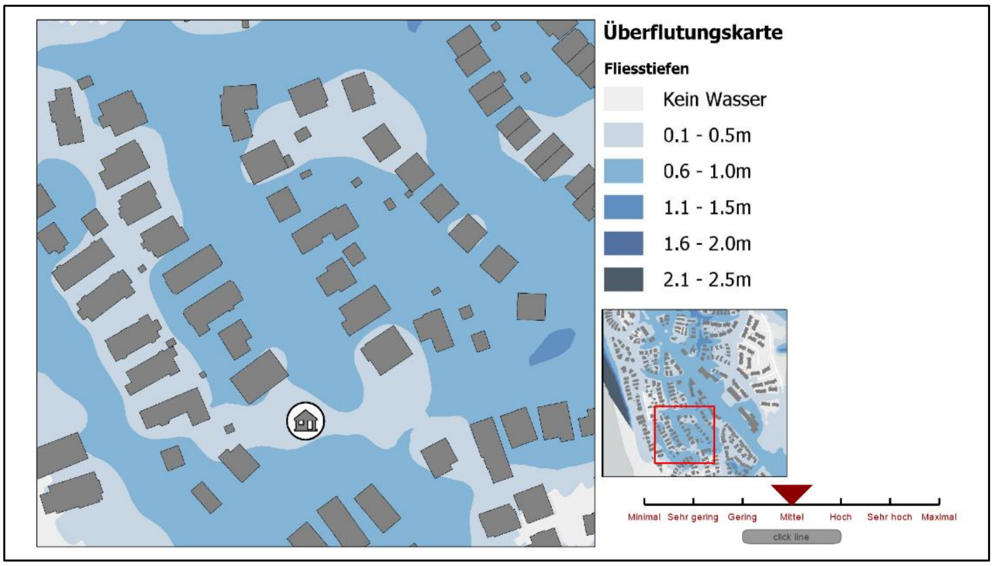
Überflutungskarte
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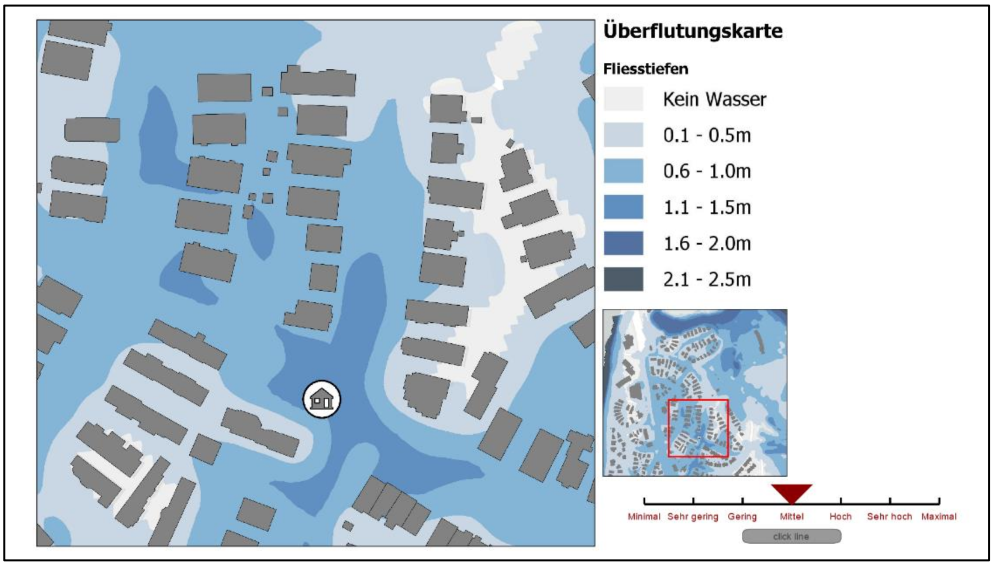
Überflutungskarte
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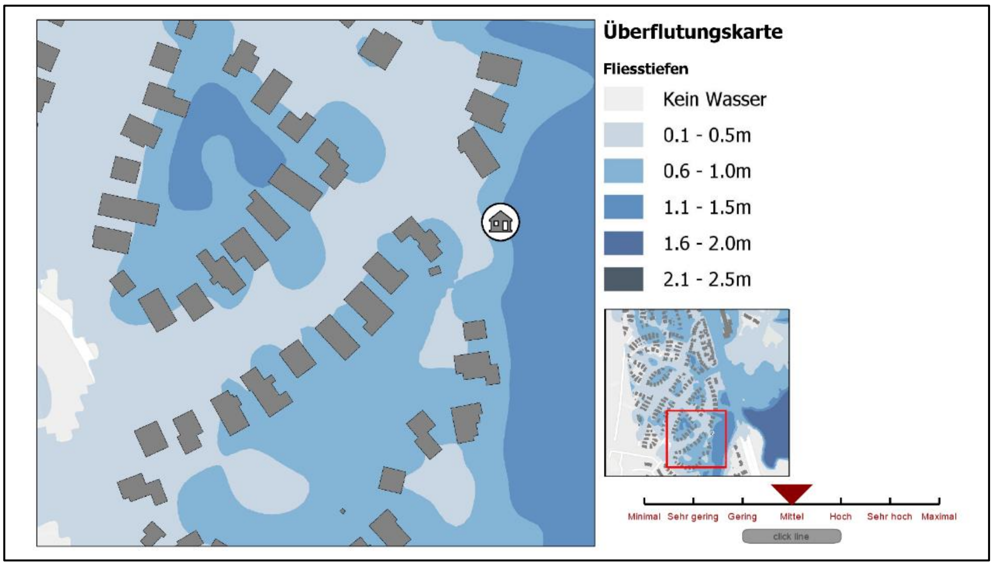
Überflutungskarte
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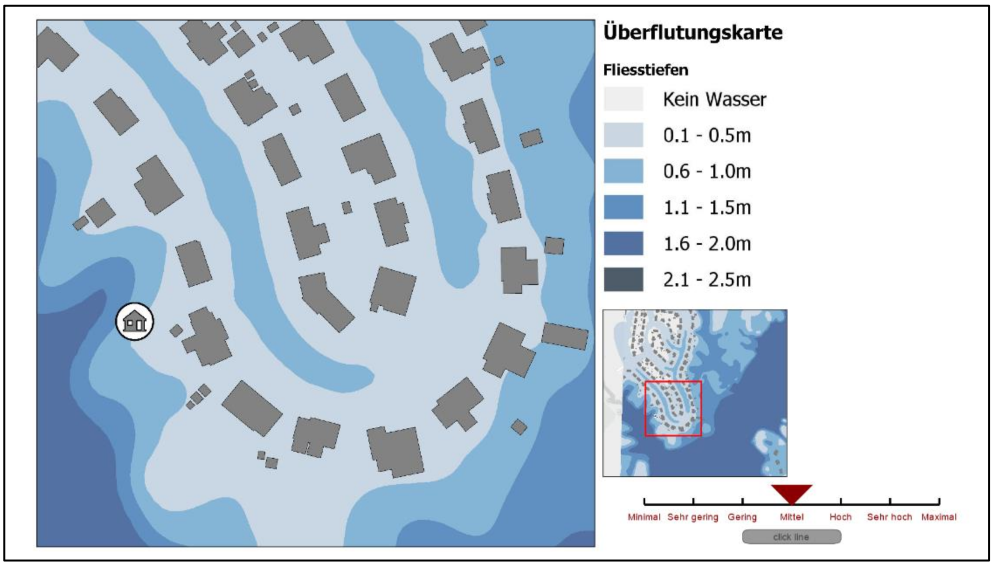
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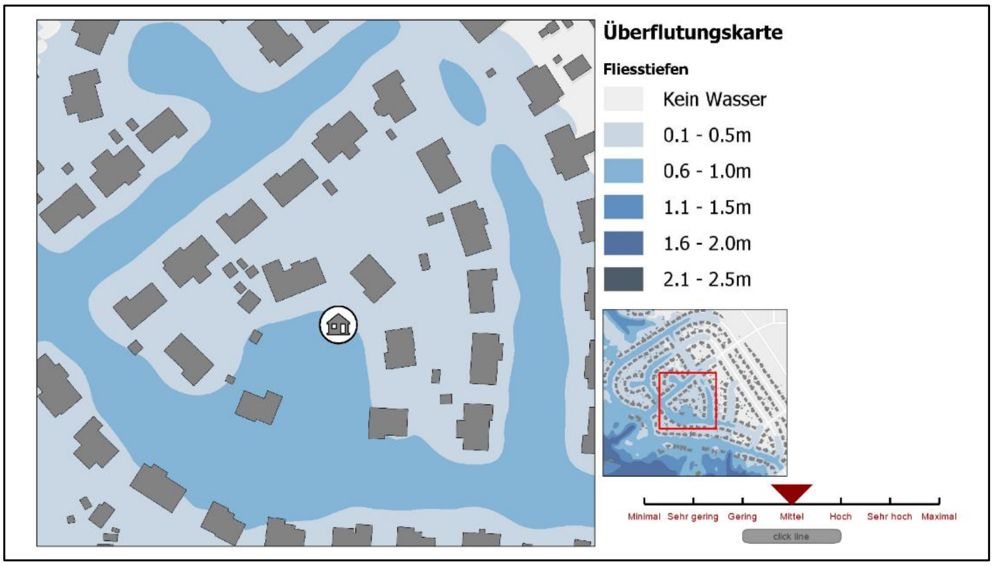
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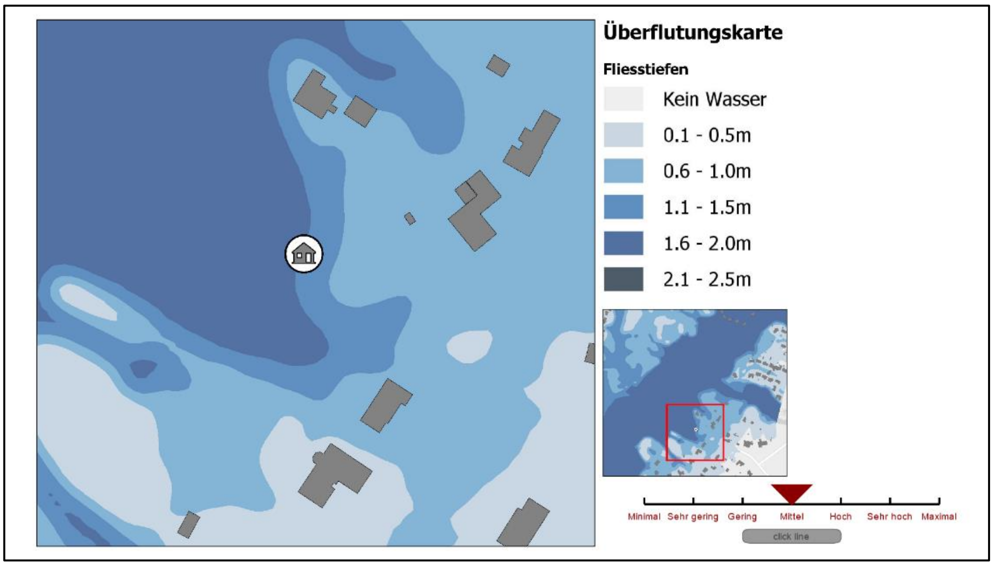
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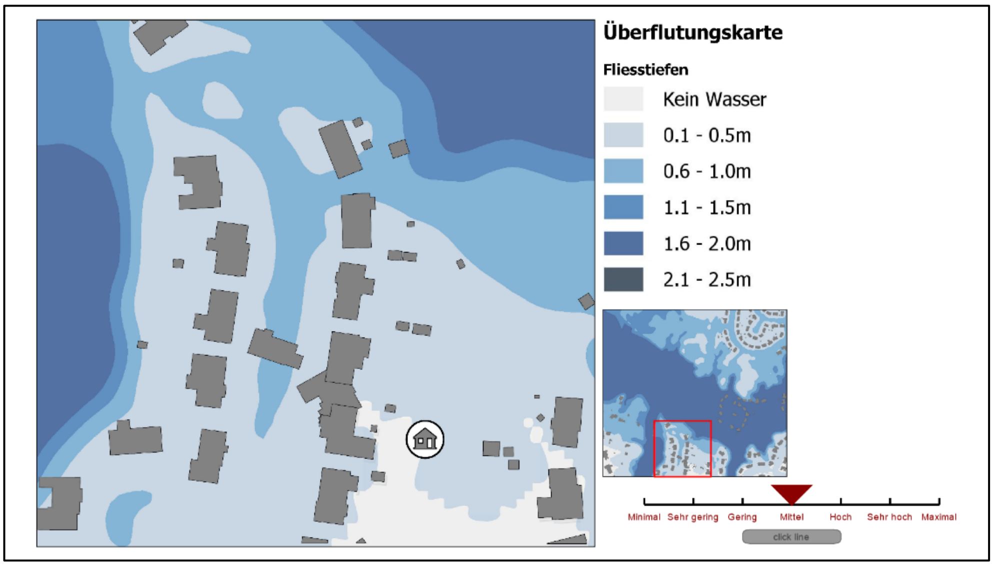
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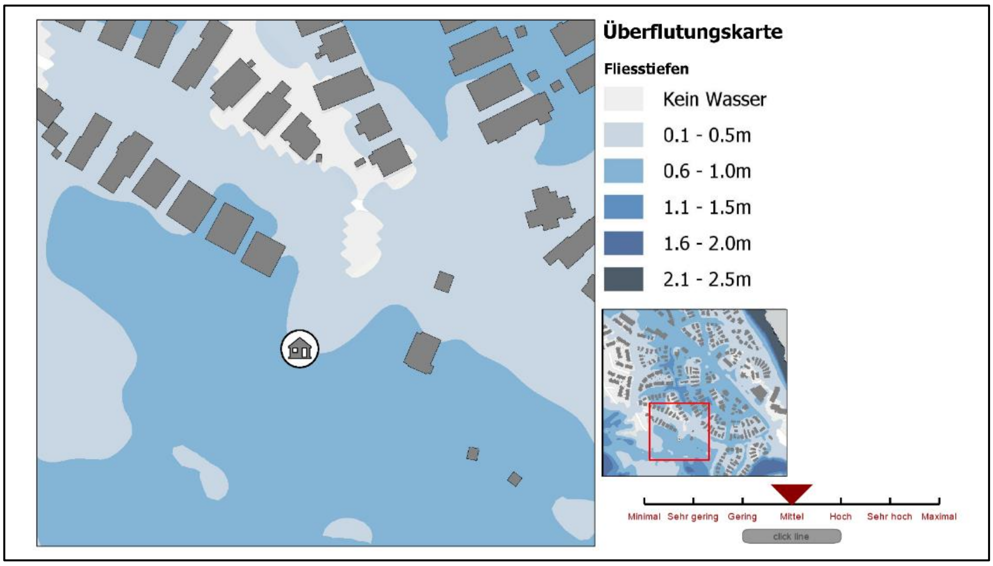
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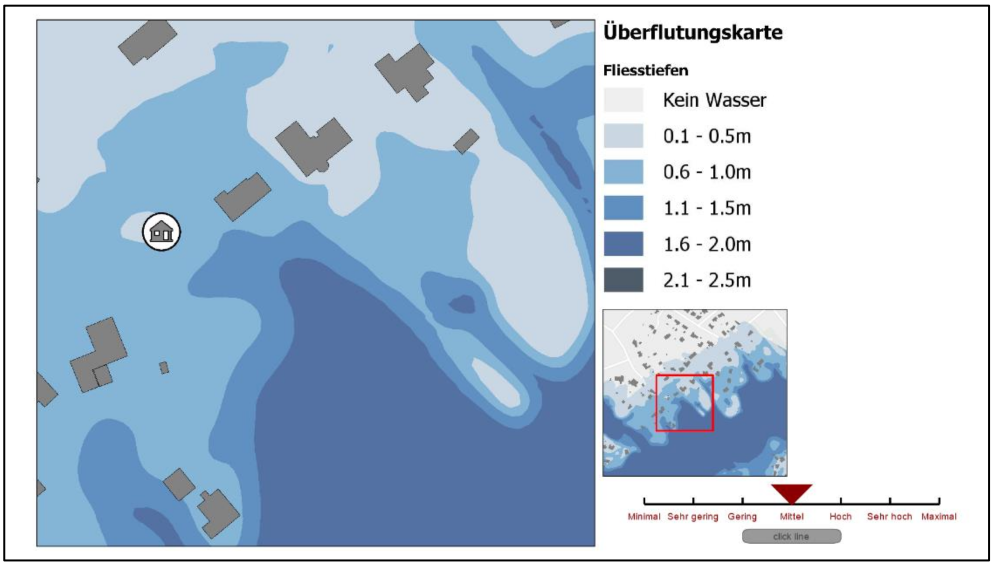
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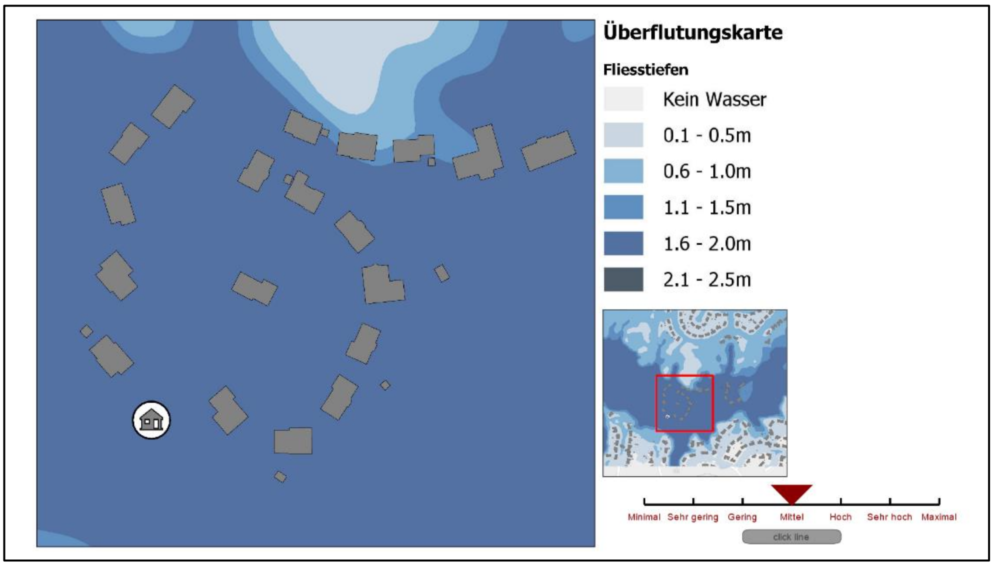
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click line

Fast fertig!
Teile dem Betreuer mit, dass du die Aufgaben gelöst hast.

Um abschliessend noch deine Vorgehensweise zu verstehen, werden dir nochmals 3 Kartenaufgaben gezeigt, die du schon einmal gesehen hast. Es ist aber kein Problem, wenn du die Karten nicht wiedererkennen solltest und deshalb nicht gleich antwortest!

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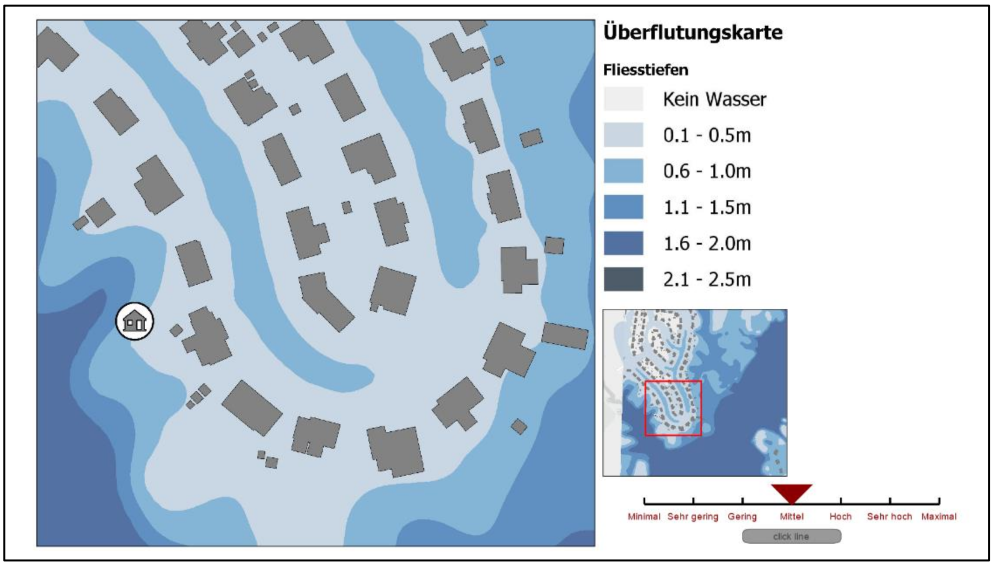

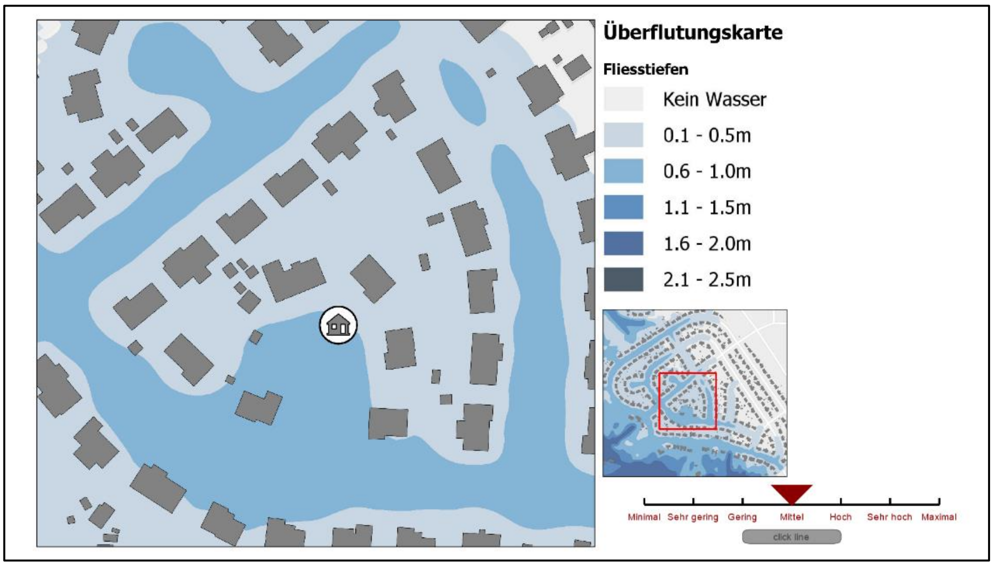

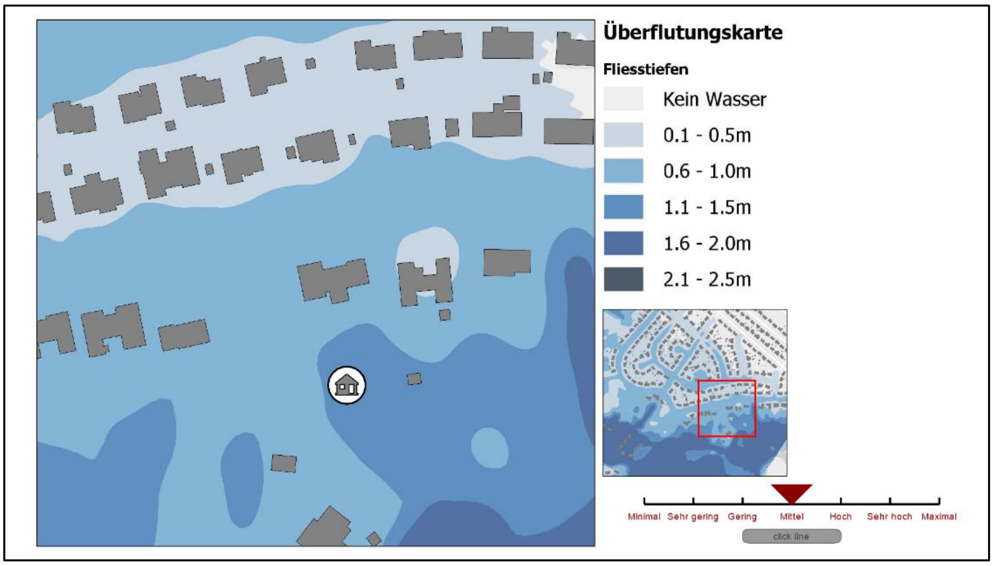
Überflutungskarte
Fliesstiefen
Kein Wasser
0.1 - 0.5m
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2.1 - 2.5m
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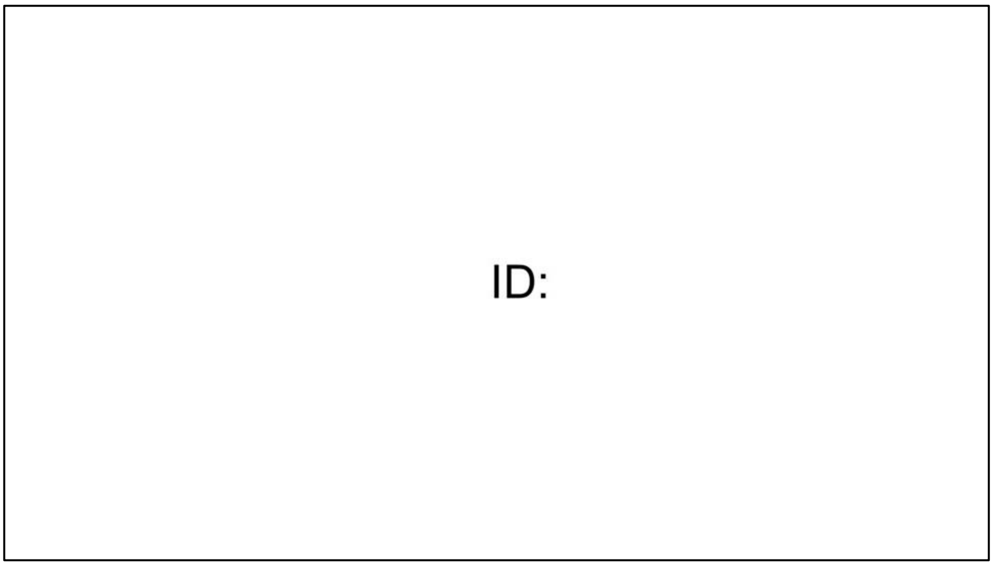
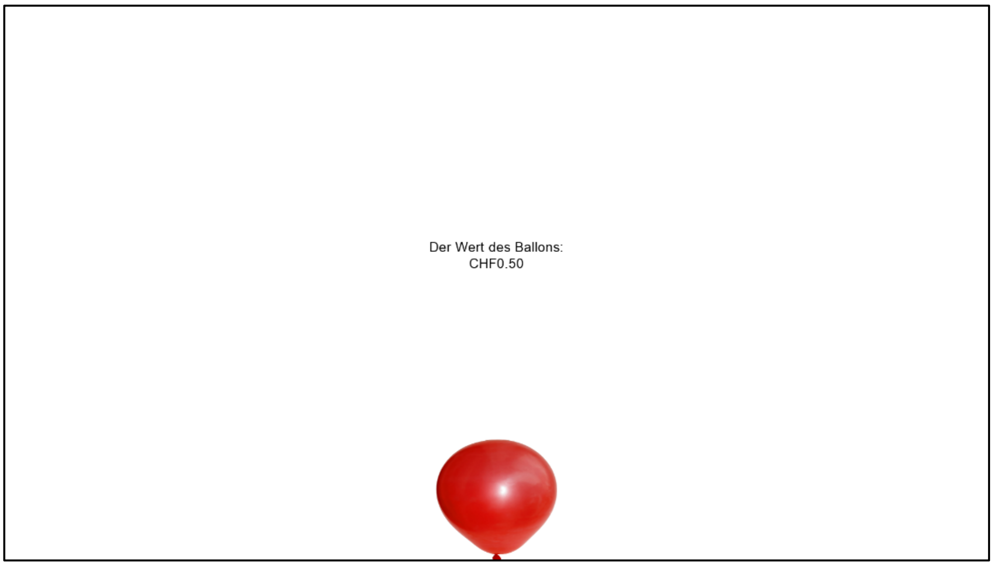
click line

VIELEN DANK!

F. Example scenario for the 2.5D group



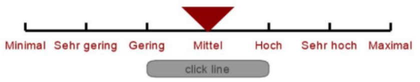


Stell dir vor du möchtest ein Haus bauen und hast bereits eine erste Vorauswahl für mögliche Standorte getroffen. Einen genauen Entscheid, wo du dein Haus bauen möchtest, konntest du aber noch nicht fällen. Da du dein zukünftiges Haus möglichst vor Überschwemmungen schützen möchtest, schaust du dir nun auch die Überflutungskarte an.

Mit der Überflutungskarte willst du herausfinden wie stark dein zukünftiges Haus dem Risiko einer möglichen Überflutung ausgesetzt ist.
Du hast insgesamt 16 Standorte gefunden, die für einen Hausbau in Frage kommen.
Deine Aufgabe ist es nun das Überflutungsrisiko für jeden dieser Haus-Standorte auf einer Skala von 1 bis 7 abzuschätzen (entspricht 16 Kartenaufgaben).

Du solltest dir also bei jeder der 16 Kartenaufgaben die folgende Frage stellen:

Wie riskant ist es, bezogen auf das Überflutungsrisiko, an diesem Standort ein Haus zu bauen?



Auf der Skala klickst du mit der Maus auf den gewünschten Wert und klickst danach wieder mit der Maus in das graue Kästchen unterhalb der Skala.

Drücke ENTER um weitere Infos zu erhalten.

Rechts siehst du die Legende der Überflutungskarte:
Die Überflutungskarte stellt die unterschiedlichen Wassertiefen
in verschiedenen Blautönen dar (je dunkler das Blau, desto tiefer ist das Wasser)

Links siehst du das Symbol, das dir jeweils den Hausstandort in den
Überflutungskarten zeigt.

In diesem Experiment wird für jede Kartenaufgabe deine benötigte Zeit gemessen.
Es besteht allerdings kein Zeitdruck für dich, da die Qualität der Entscheidung stets
im Vordergrund stehen sollte. Mache also zum einen keine überstürzten Entscheide,
aber verbringe zum anderen nicht zuviel Zeit an einer einzelnen Kartenaufgabe.
Es gibt weder Richtig noch Falsch bei deiner persönlichen Risikowahrnehmung.

WICHTIG:
Die Überflutungskarte zeigt ein 100-Jahresereignis. Das bedeutet, dass
statistisch gesehen einmal in 100 Jahren ein solches Ereignis auftreten könnte.
Allerdings kann es auch mehrmals innerhalb dieser 100 Jahren auftreten oder auch nie!

Bevor du mit den 16 Kartenaufgaben beginnst, wird dir als nächstes eine Übersichtskarte
gezeigt, bei der du sehen kannst, wie die Überflutungskarte zusammen mit der Legende
im Allgemeinen aussieht. Danach kannst du zwei Aufwärmübungen machen, um dich
an die Skala zur Risikoeinschätzung zu gewöhnen. Nach den zwei Aufwärmübungen hast
du noch die Gelegenheit Fragen zu stellen, bevor es mit den 16 Kartenaufgaben losgeht.

Falls du jetzt Fragen hast, kannst du diese natürlich stellen.

Drücke ENTER um zunächst die Übersicht über die Überflutungskarte
zu sehen. Danach kommen die zwei Aufwärmübungen.

Kein Wasser
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0.6 - 1.0m
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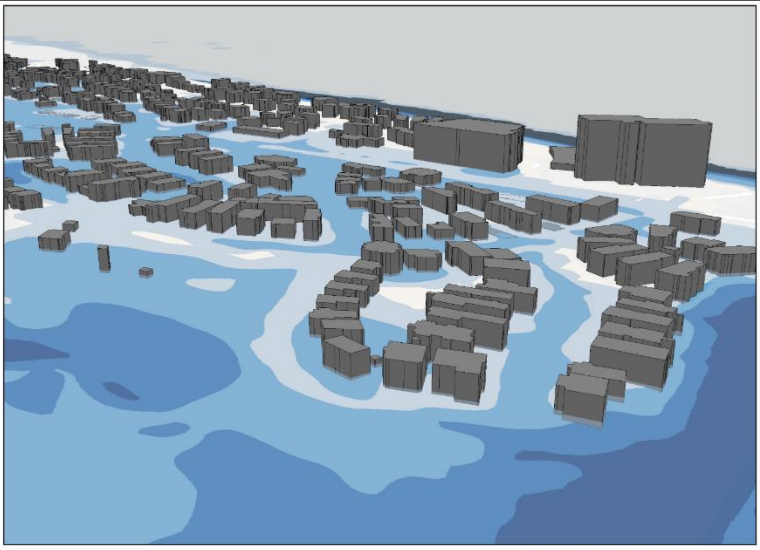

Fliesstiefen

Kein Wasser
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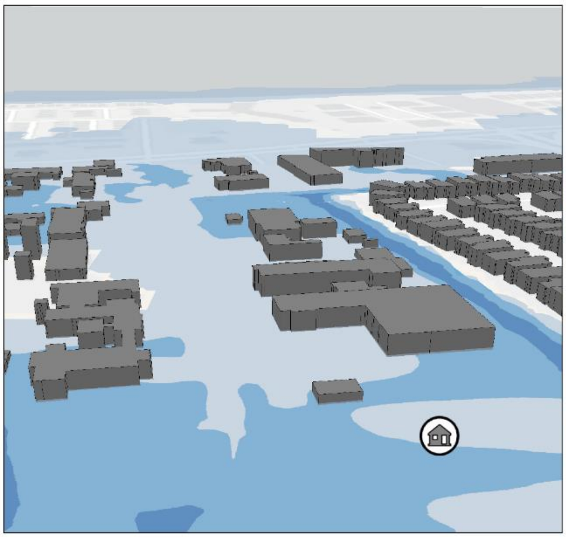

Aufwärmübung

Fliesstiefen

Kein Wasser
0.1 - 0.5m
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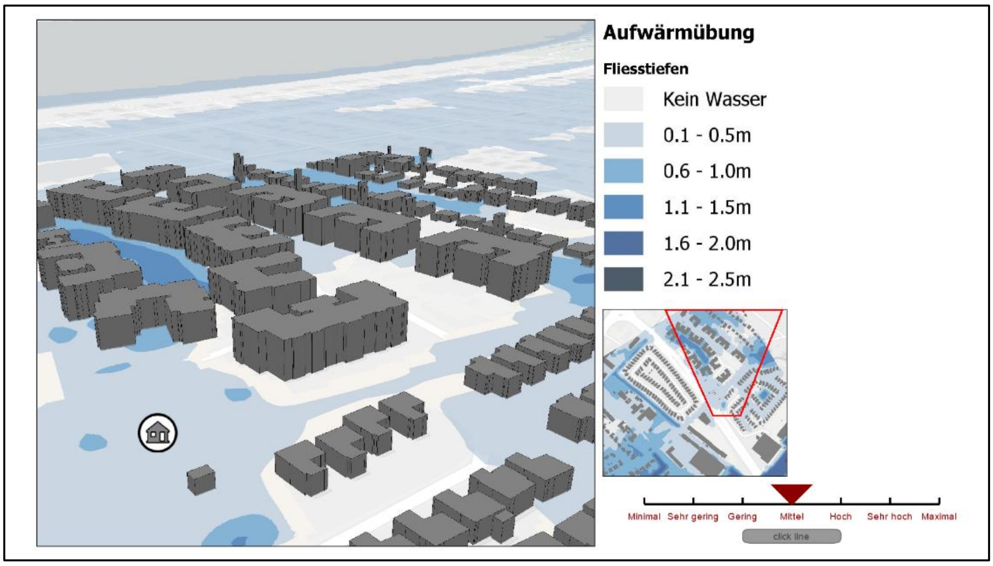
Aufwärmübung
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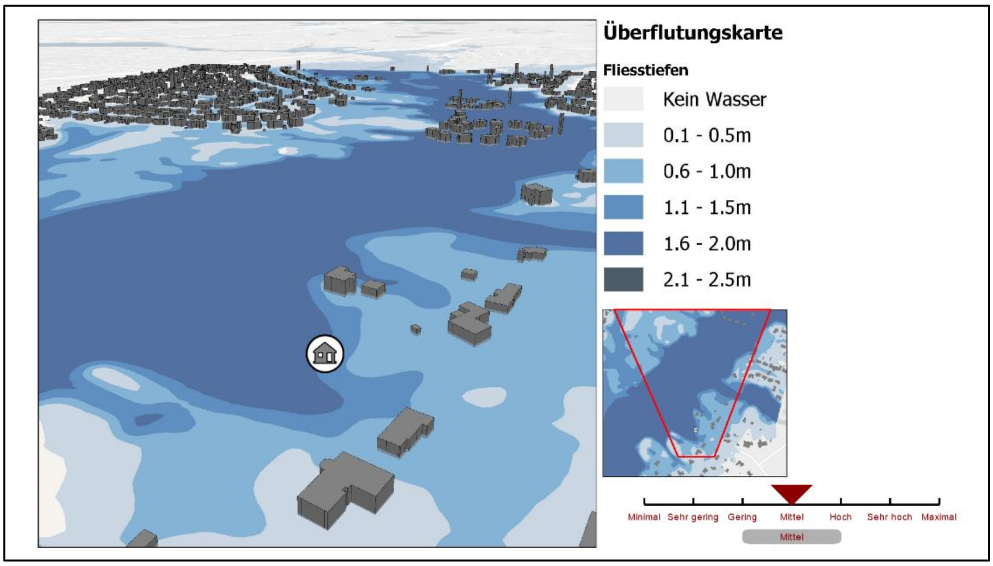
Start
Hast du noch Fragen?
Sobald du ENTER drückst, wird das Experiment starten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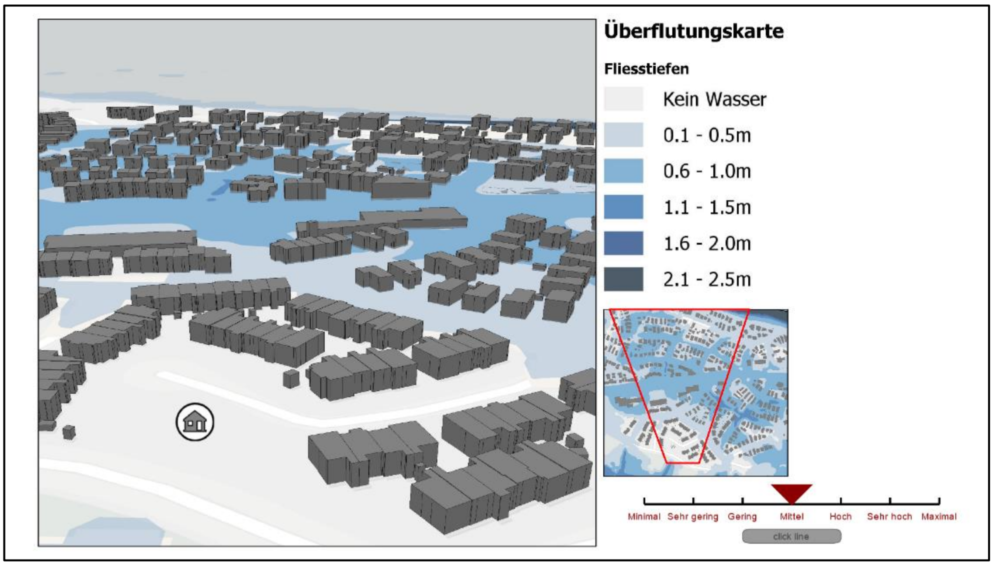
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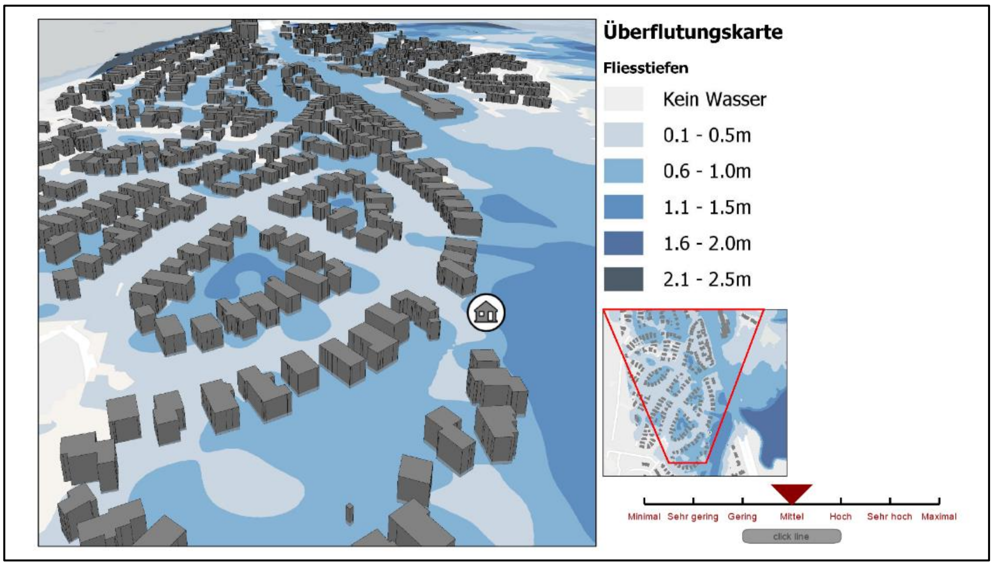
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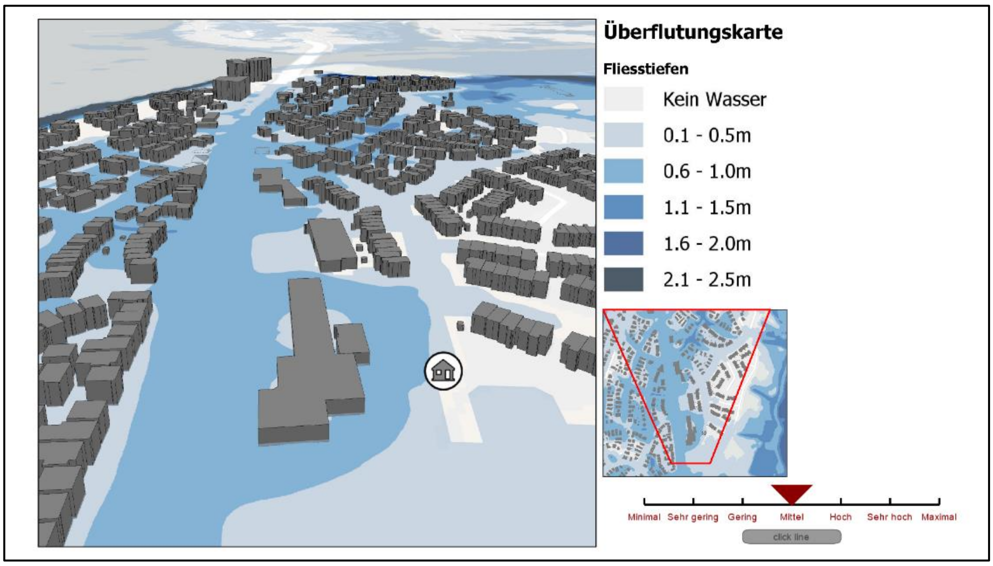
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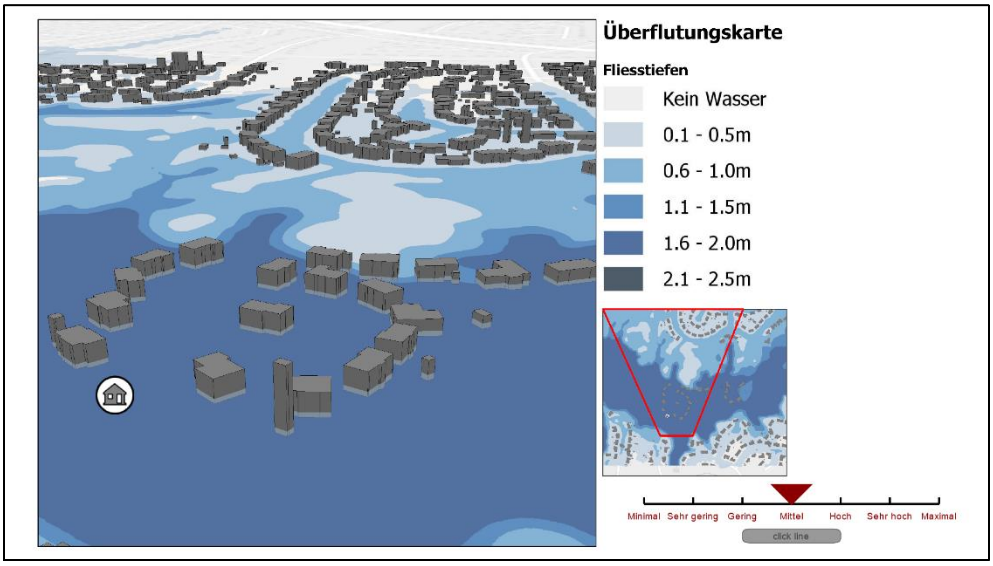
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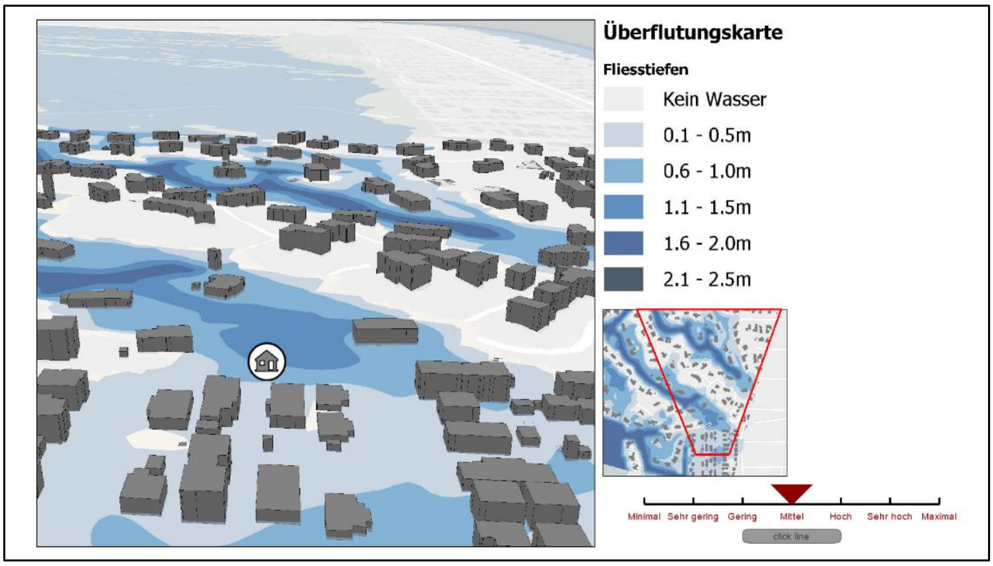
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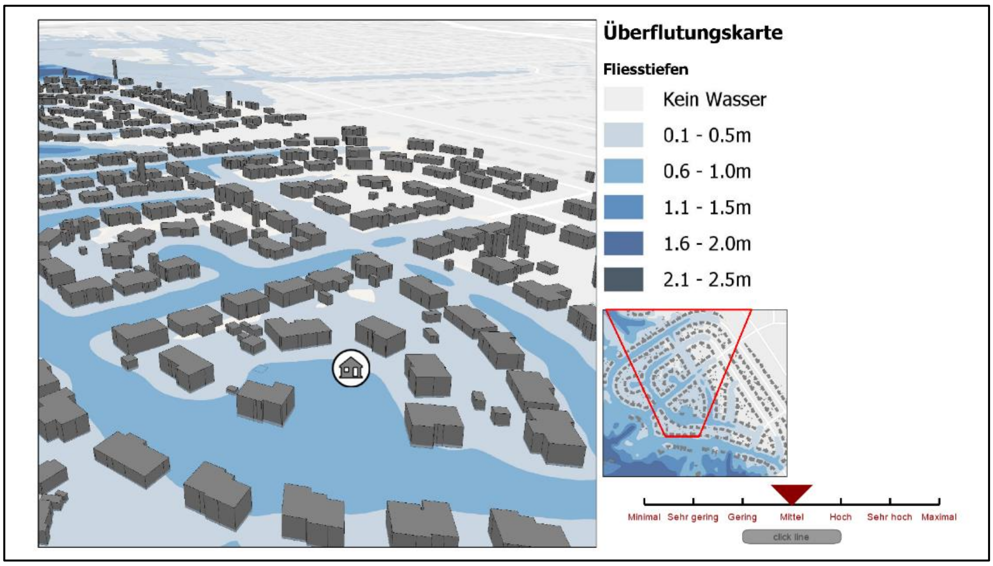
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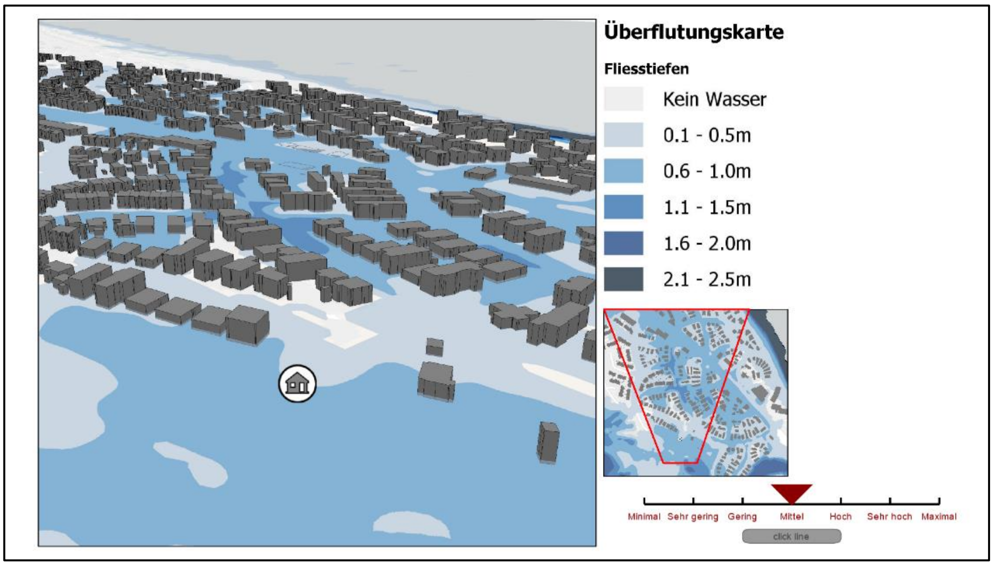
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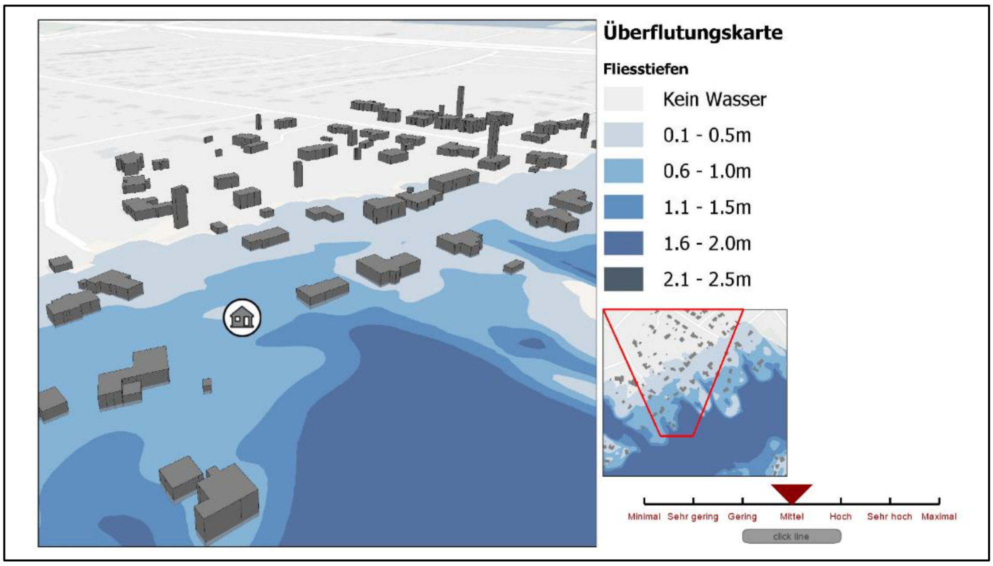
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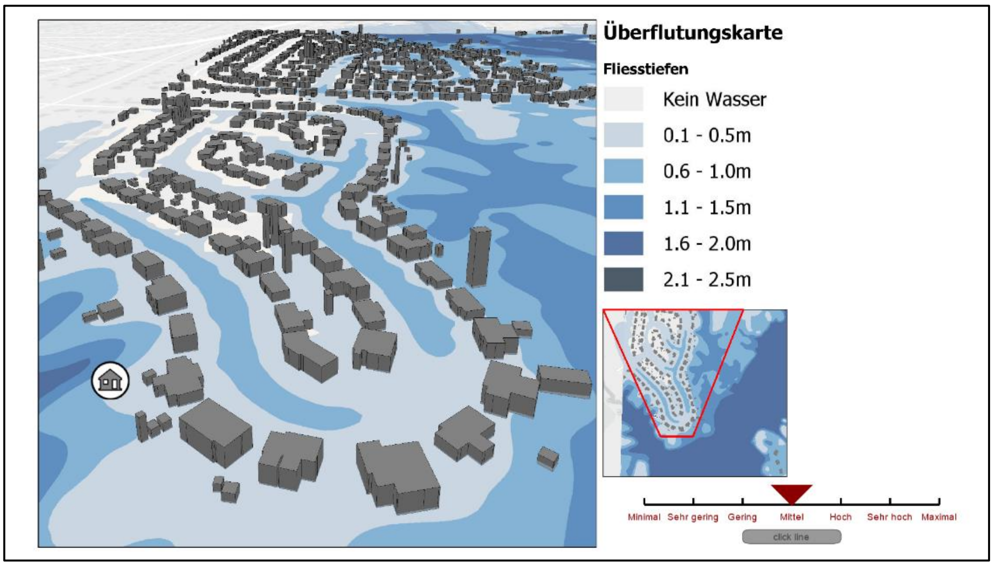
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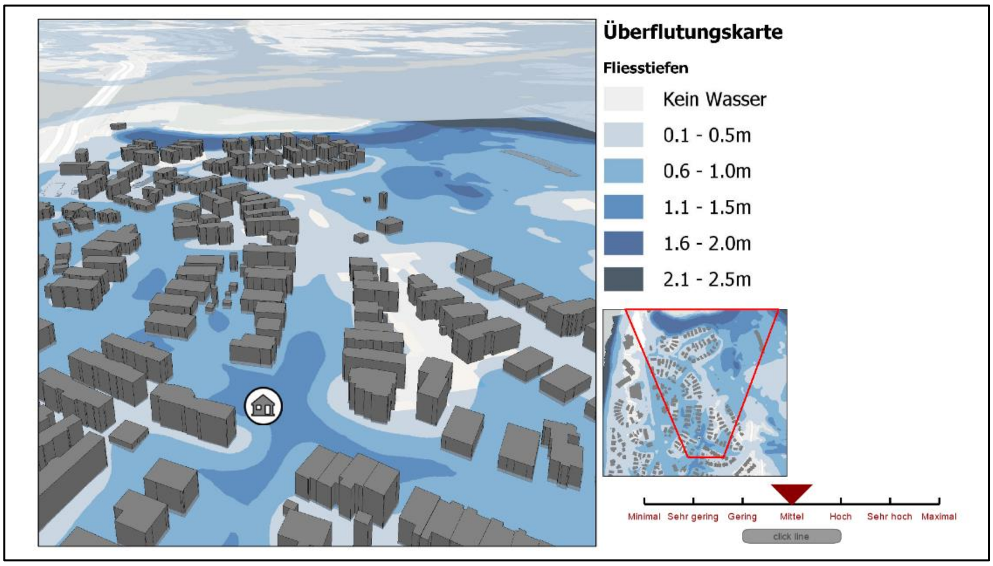
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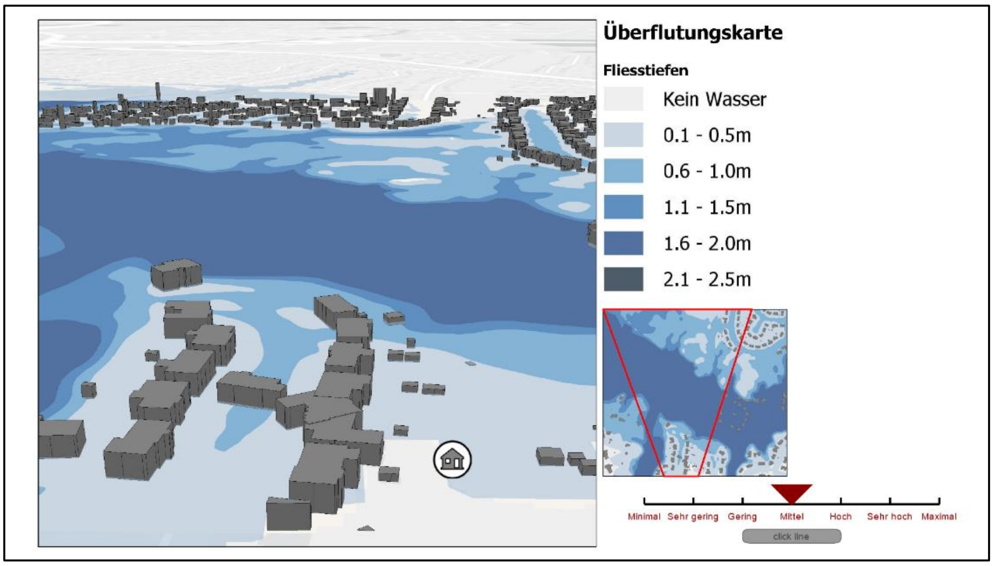
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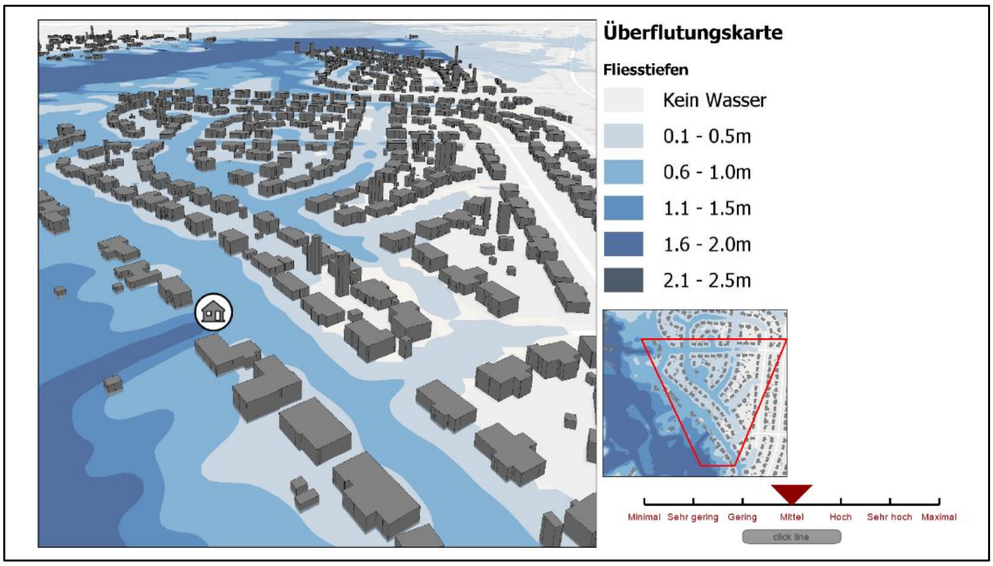
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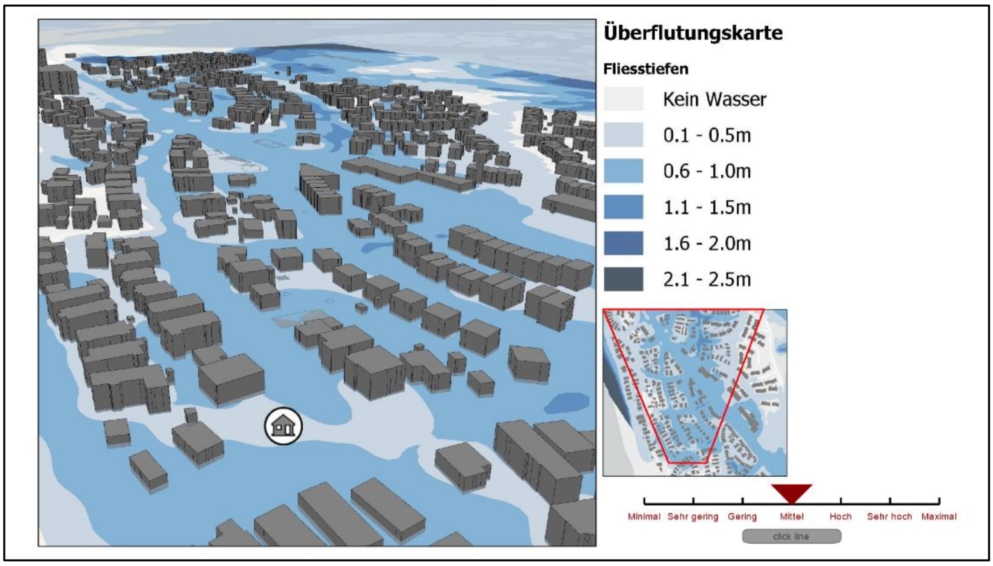
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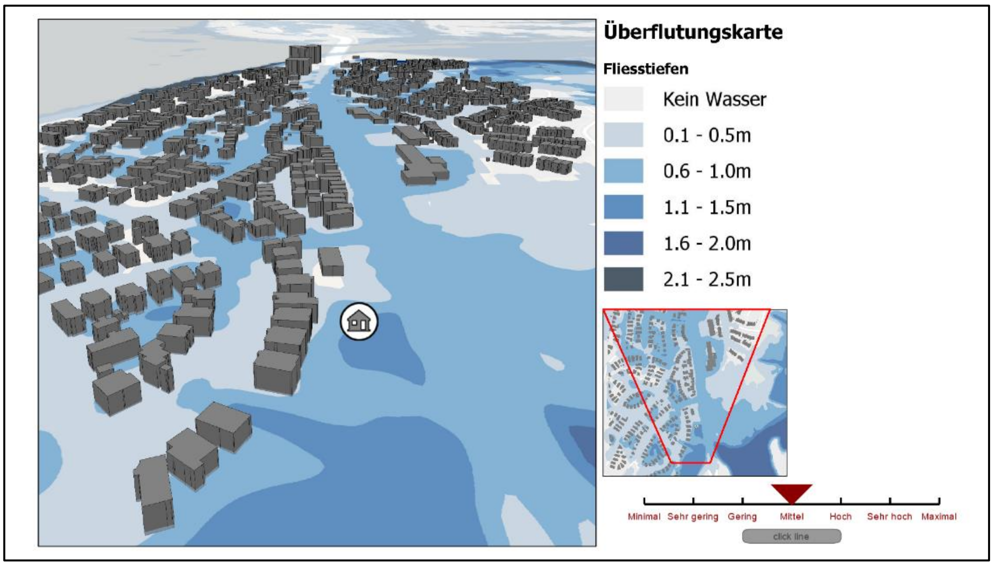
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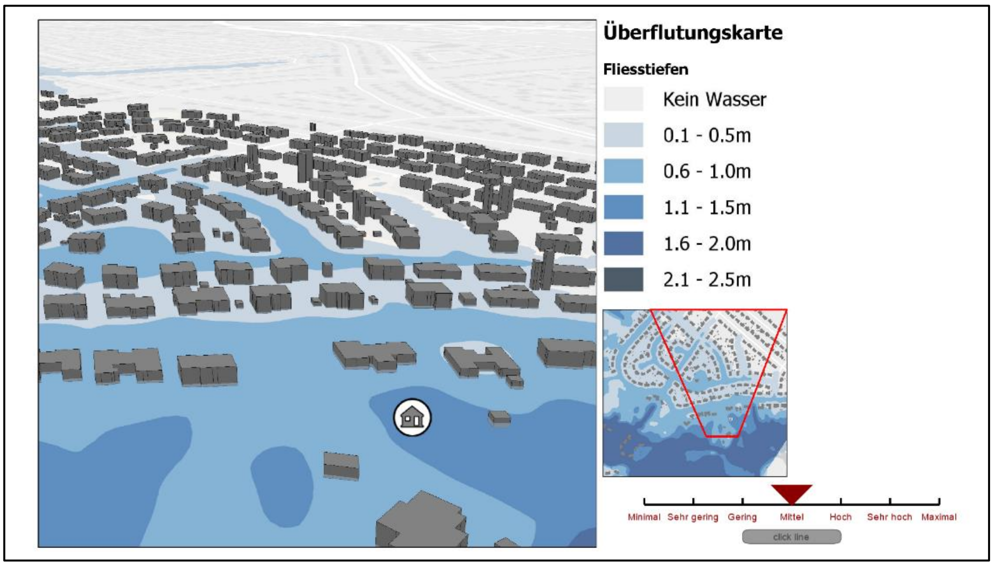
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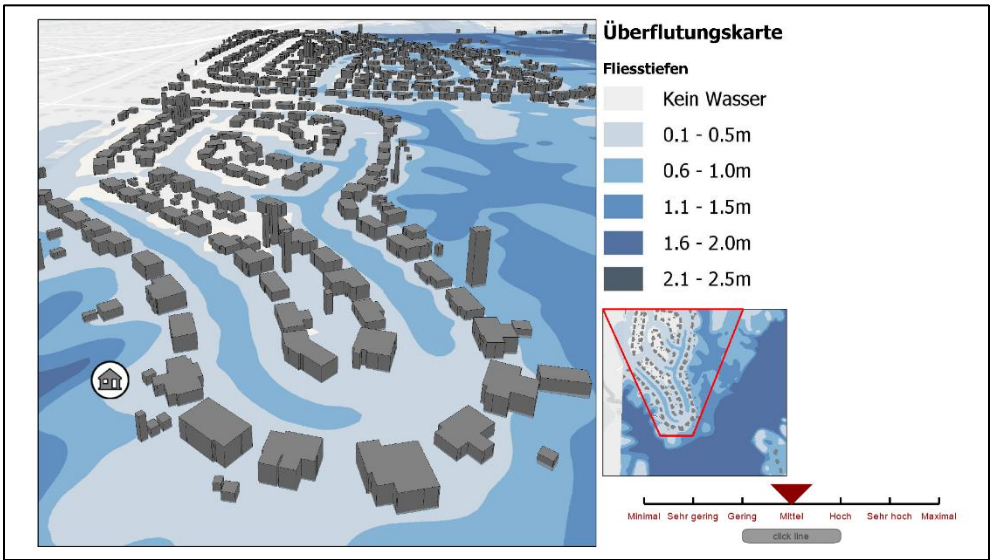

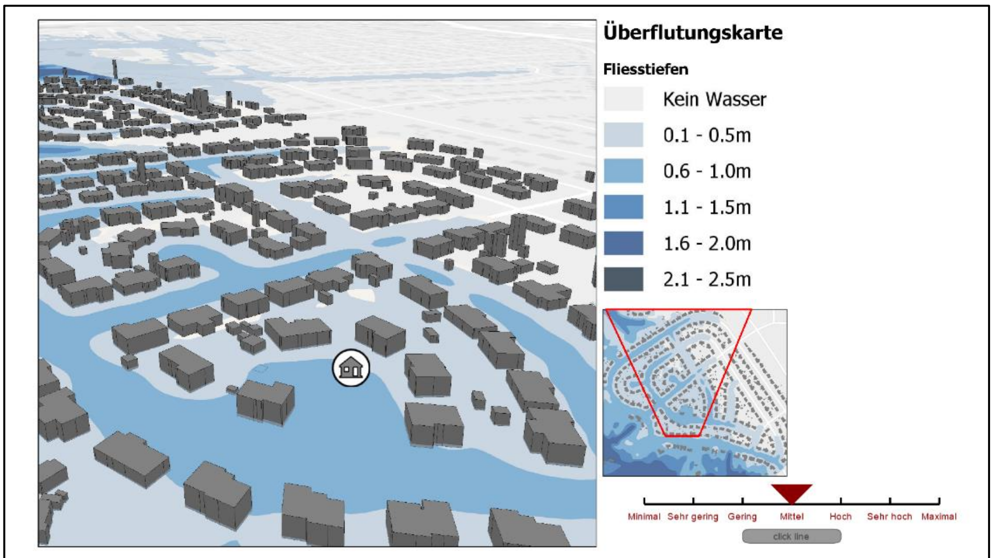

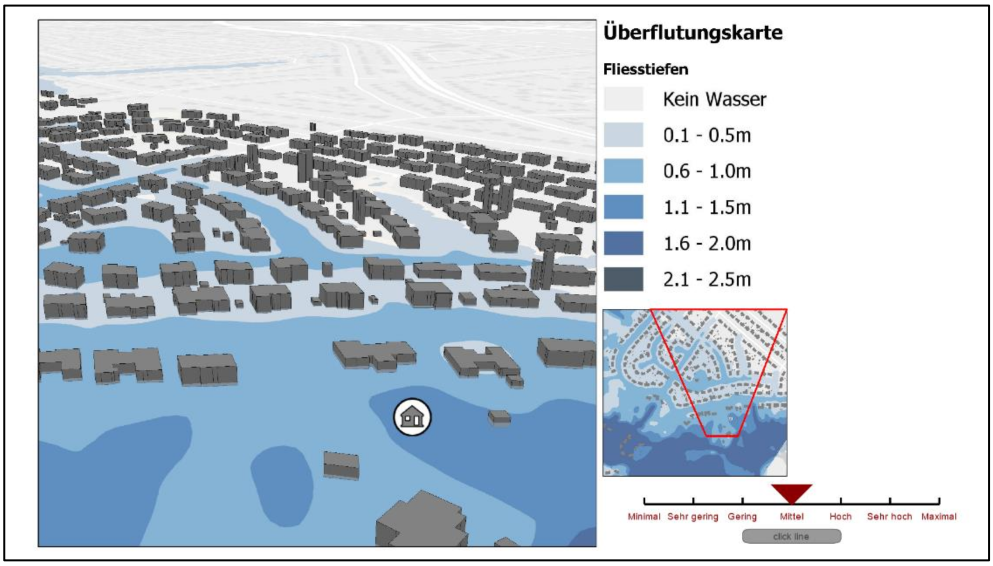

Überflutungskarte
Fliesstiefen
Kein Wasser
0.1 - 0.5m
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Minimal
Sehr gering
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VIELEN DANK!

G. Think aloud transcripts

1

Also ich würde hier ehrlich gesagt kein Haus bauen, da die Überflutungsgefahr ist so hoch, sie ist ja in drei Stufen drin. Und wegen dem würde ich das eh als sehr hoch einschätzen und ich würde da kein Haus bauen, weil ich kein Risiko eingehen will, obwohl es nur einmal in 100 Jahren kommen würde oder nie. Aber man weiss es halt nicht.

Also hier würde ich beim zweiten Bild. Es ist eigentlich so ein bisschen der Durchschnitt, also so gering bis sehr gering, dass die Überflutung kommen würde. Und es sind schon ein paar Häuser angesiedelt. Also das ist schon mal ein Punkt, dass andere schon etwas gebaut haben dort und damit eigentlich auf dem sicheren Weg sind und nicht dran glauben, dass dort etwas kommen würde. Deshalb wäre es für mich eine sehr geringe Gefahr für eine Überflutung.

Dort würde ich es mir ehrlich gesagt zweimal überlegen, bevor ich etwas mache. Weil wenn ich es auf der kleinen Karte anschaue, sehe ich dass es eigentlich ziemliche Überflutungsgefahren gibt. Und das muss ja nicht heissen, dass es dort stoppt auf dieser Karte, es kann ja weitergehen. Eine Karte bestimmt ja nie die Grenzen in diesem Sinn. Für mich wäre eigentlich dort wieder hoch bis sehr hoch in diesem Sinne.

2

Also hier ist es schwierig, weil das Piktogramm in mehrere verschiedene Farben hineinschaut. Da habe ich einfach etwas aus der Mitte genommen. Also ich habe hoch genommen, weil es schon in das Dunkelblaue hineingeht.

Beim Zweiten geht es so vom Grauen zum Hellblauen, ist so ein bisschen in der Mitte. Da habe ich es als Mitte eingeschätzt.

Beim Dritten ist es eigentlich tief im Blauen drin, aber nicht ganz Dunkelblau. Aber eigentlich würde ich das schon als Hoch einschätzen.

3

Zuerst schaue ich auf die Wassertiefe. Das Haus ist in 0.6-1.0m Wassertiefe. Das ist gar nicht so schlimm, aber es ist sehr nahe an der nächsten Stufe. Und vor allem in der Übersichtskarte nebendran versuche ich zu schauen, woher das Wasser kommt und wohin es fliesst bei starkem Regen. Das scheint mir hier zu sein, als ob es ablaufen würde. Aber wir sind als sehr nahe an einer Senke wo das Wasser hineinläuft, deshalb würde ich zwischen hoch und sehr hoch tendieren. Weil wir aber doch oben am Hang sind, gehe ich auf hoch.

Das nächste Bild erinnert mich fast ein bisschen an Venedig. Es sieht mir nach einem Kanalsystem aus. Es ist aber mitten in den Häuser drin und wo sind wir in den Wassertiefen… wir sind zwischen 0.5-1.0m… eher im 0.6-1.0m Bereich. Also auch hier ein Hoch. Denn wenn es mal Wasser gibt, dann läuft es wohl nicht so schnell.

Dann das letzte Bild. Das ist eher eine nicht so hübsche Situation. Da würde ich auf sehr hoch bis maximal gehen, da wir in noch tieferem Wasser sind. Und sind sogar in einem Bereich wo es sich entweder sammelt oder woher das Wasser dann auch kommen würde, wenn es z.B. vom Meer her lauft. Deshalb gehen wir hier mal auf sehr hoch.

4

Mein Haus ist in der Nähe von anderen Häuser. Und es ist an der Grenze von verschiedenen Fliesstiefen. Es ist als risikoreicher einzustufen als die Häuser die Richtung Osten sind. Das heisst, ich würde die Gefahrenstufe als hoch einschätzen.

Das Haus ist wieder in der Mitte von anderen Häuser. Also es wird umkreist. Aber die anderen Häuser sind in einem Bereich, der nicht sehr gefährlich ist. Der Schaden an deinem Haus wird nicht durch andere verursacht. Dein Haus ist relativ weit entfernt von den unteren Häusern, welche relativ gefährlich werden könnte. Deshalb würde ich sagen, das Risiko bei diesem Haus ist gering, weil es trotzdem noch an der Grenze ist zur dritten Kategorie gering und nicht sehr gering.

Dann das letzte Haus ist… in einem Gebiet wo die Fliesstiefe relativ gross ist. Der Abstand zu den anderen Häusern ist wieder gegeben mehr oder weniger. Ich würde dies als mittel einstufen, weil die anderen Häuser auch…also nicht gefährlich, aber relativ… also sie sind nicht im geringsten Fliesstiefenbereich, das heisst Schäden könnten von diesen Häusern kommen. Darum mittel.

5

Also, es kreuzt an sehr tiefem Wasser und ist ziemlich nahe vom sehr tiefem Wasser bis 2m und deshalb habe ich das als sehr hoch eingestuft.

Hier stufe ich es als gering ein, da das Wasser nicht sehr hoch ist und die Häuser recht stabil gebaut werden.

Hier stufe ich es als sehr hoch ein, weil es komplett im normalblauen Bereich ist und das schon sehr hohes Wasser ist, 1.5m.

6

Ja da habe ich geschaut was auf der grossen Karte ist. Also da ist es in der Umgebung der grossen Karte relativ dunkel und deshalb habe ich ein etwas höheres Risiko gewählt, als die Karte eigentlich anzeigt. Aber trotzdem glaube ich es ist gering.

Hier sind wir relativ weit weg von den ganz grossen Tiefen und am Rand von diesen 0.6 Meter. Deshalb mache ich hier sehr gering…hoffentlich.

Hier sind wir zwar in einem Bereich wo das Wasser ein wenig tiefer ist, aber trotzdem weit weg von ganz grossen Tiefen, deshalb ist dort wahrscheinlich mittel.

7

Grundsätzlich habe ich immer geschaut, ob es im Überschwemmungsgebiet liegt. Das ist hier der Fall. Die Risikoeinschätzung, welche ich nachher vorgenommen habe, ist am Ausmass der Schäden gemacht. Da ja 0.1 bis 0.5m eher nicht so hoch ist. Hier sind wir jetzt in einer Zone wo das Haus zwischen mehrerer Zonen drin liegt. Also zwischen der tiefsten, zweittiefsten und dritttiefsten und deshalb hätte ich das jetzt als mittel bis hoch eingeschätzt. Also mittel weil der grösste Teil im mittleren Bereich liegt.

Bei der zweiten Karten ist eine geringe oder eine mittlere Überflutung. Hier schätze ich das Risiko als mittel ein, weil ich vorhin es als hoch eingeschätzt habe.

Bei der dritten Karte sind wir wirklich in einem 1.1 bis 1.5m Bereich. Also es wird auch sonst mal ab und zu eine Überschwemmung geben und 1.5m ist dann doch relativ hoch und deshalb habe ich dort das Risiko als sehr hoch eingeschätzt.

8

Es ist zwischen dem zweittiefsten und dem dritttiefsten. Deswegen ist es sicher nicht minimal. Es ist zwischen gering und sehr gering. Weil es aber nahe ist zum nächsthöchsten wähle ich gering.

Das nächste ist im Bereich zwischen 0.6 und 1. Aber sehr nahe am zwischen 0.1 und 0.5 und deswegen würde ich das schon als sehr gering einschätzen.

Das nächste ist zwischen 1.1 und 1.5. Rund herum ist es zwischen 0.6 und 1. Das würde ich als hoch einschätzen, aber noch nicht sehr hoch, weil es noch nicht in der dunklen Farbe ist.

9

Das ist jetzt nicht so… ja es mittleres Risiko… ja bis gering, weil es noch in dieser hellen Zone drin ist.

Hier finde ich es eigentlich sehr gering. Es ist zwar die gleiche Farbe wie vorhin, aber es hat nicht so viel Dunkelblau drum herum, von dem her ist es eher noch weniger gering als beim vorherigen.

Dort finde ich es eher hoch, denn wenn ich die kleine Karte anschaue wo der ganze Ausschnitt gezeigt wird, ist es unten ziemlich dunkelblau und der Standort ist eher im Ausläufer und deshalb kann ich mir vorstellen, dass es eher noch eine Überflutung geben könnte.

10

Ich habe mir so ein bisschen überlegt, dass ich die Werte eigentlich den Worten zuordne. Also für mich ein Wert entschieden habe, der für mich mittel ist und einer der für mich hoch ist. So ungefähr. Also das erste wo kein Wasser hat, ist für mich minimal. Und dann kommt halt so ein bisschen die Kombination, je nachdem ob es ein oder zwei von diesen Werten hat.

Dort hat es jetzt mehrere. Dort habe ich jetzt gesagt, dass Risiko ist mittel bis hoch, weil es zwar noch in diesem Bereich ist wo es nicht so viel hat, aber angrenzend an einen Ort wo es viel ist (1.6).

Dort muss ich zuerst schauen, ob das helle wirklich kein Wasser ist. Das ist es nicht, das heisst es ist das 0.1-0.5m. Es grenzt aber auch noch an 0.6-1.0m. Daher würde ich sagen, es ist gering.

Das ist jetzt eher höher. Sicher hoch, weil es schon bei 1.1-1.5m ist, aber auch noch ein bisschen angrenzend… sehr hoch… nein nein, hoch. Es ist ja nur einmal alle 100 Jahre.

11

Also da ist es hoch, weil es viele Dunkelblaue darum herum hat. Es ist zwar im geringen Bereich, aber rund herum könnte es zu Überflutungen kommen, da es dunkelblau ist.

Dort ist es eher gering, weil es steht im Bereich wo es keine Überschwemmungen gibt, gemäss Statistik. Der blaue Bereich ist relativ weit entfernt, also das Dunkelblau.

Dort ist es hoch. Dort würde ich maximal sagen.

12

Ok, meine Denkweise ist halt, dass ich nur auf die Farbe auf der Karte an der Stelle vom Haus anschaue. Ich versuche so objektiv wie möglich zu betrachten, dass wenn es statistisch gesehen wenig hoch kommt, dann ist die Chance sehr gering und dann bin ich mehr bereit das einzugehen. Mein Faktor ist eigentlich nur die jeweilige Farbe. Man muss aber natürlich sagen, dass auch wenn es irgendwie nur ein Meter ist, dass das auch schon nicht gut ist. Also eigentlich ist ein Meter oder zwei Meter… ist eigentlich beides schlecht. Aber… ähm… ich bin halt ein Draufgänger.

13

Also zuerst habe ich den kleinen Kartenausschnitt angeschaut mit der grossen Übersicht drauf und dort sehe ich, dass halt bis zu 2 Meter Tiefgang ziemlich nahe an mein Haus rankommt, aber ich in der Phase bis zu 0.1-0.5m bin. Aber weil das alles sehr nahe zusammen ist und es eigentlich ziemlich tief runter geht, habe ich dort eher ein hohes Risiko genommen. Und würde dort kein Haus bauen.

Hier habe ich auch wieder den Kartenausschnitt mit der grossen Übersicht angeschaut. Dort sieht man, dass die ganze Überbauung ein bisschen auf einer Insel steht, wo nur 0.1-0.5m Wasser kommen könnte, aber das Haus ist gerade so an der Ecke zu 0.6-1.0m Hochwasser. Eher ein geringes Risiko, weil so ein Drittel vom Haus eher nicht vom Hochwasser betroffen sein wird mit 0.1-0.5m. Eher gering.

In der nächsten Karte habe ich auch wieder die grosse Übersicht angeschaut zum Schauen wo das Wasser herkommt und wo es richtig tief ist. Ich habe geschaut wie das Wasser in die ganze Überbauung oder in das ganze Quartier fliessen würde und ich bin hier mit dem Haus wirklich ziemlich am Rand, wo wirklich ein hohes Hochwasser bis zu 2m stattfinden könnte. Und deshalb auch wieder ein hohes Risiko für mich und mein Haus. Es ist schlimmer, als wenn ich es weiter hinten gebaut hätte und deshalb auch wieder ein hohes oder sehr hohes Risiko.

14

Also ich habe Mittel genommen, weil es eigentlich an einen Ort mit sehr wenig Wasser angrenzt, aber auch an einen Ort mit viel Wasser, aber es sieht mehr so aus, als würde es nach dem Haus stauen, wenn es eine Überflutung gibt und deswegen ist es nur Mittel weil es nur bis… ja… knapp 50cm gehen würde.

Ja da haben wir auch Mittel. Weil es ganz viele Häuser rundherum hat, was heisst, dass dies sicherlich etwas ist was blocken würde und es liegt zwischen zwei Zonen wo relativ wenig Fliesstiefen haben, wenn es ein Hochwasser gibt. Von dem her gesehen… Mittel.

Relativ hohes Risiko, weil es liegt in einer Zone wo es bis zu 1.5m Fliesstiefen hat. Es ist eher ein bisschen am Rand, also das heisst weg von der Agglomeration. Das heisst, das Wasser wird wahrscheinlich von dieser Seite herkommen, weil es vor dem Haus mehr Tiefe hat. Also das heisst, dort würde es sich sammeln und deshalb wäre die Chance, dass ich Hochwasser hätte, relativ hoch.

15

Ich schaue meistens zuerst die Übersichtskarte an und dann hat man einfach mal einen Überblick. Das Erste ist schon einmal in der Nähe von viel Wasser, aber nachher sieht man es ist nur an der Grenze zu 0.5 bis 0.6m, was nicht so viel ist und deshalb würde man es als gering einschätzen.

Bei der nächsten Karte dasselbe. Es ist eigentlich eine ähnliche Situation, nur dass es diesmal weniger blau aussieht. Weil der Ausschnitt so gewählt ist, dass hinten nicht mehr so viel Wasser… mögliches Wasser ist. Aber grundsätzlich ist es eine ähnliche Situation. Darum mache ich hier auch gering.

Hier sieht es schon mal blauer aus. Die Wassertiefe wäre auch tiefer und die anderen Häuser stehen eher im Trockenen im Vergleich. Darum würde ich hier eher hoch ankreuzen.

16

Beim ersten Bild, also bei der grossen Aufnahme, sehe ich dass es so am Rand ist und wo ziemlich viel Wasser kommen könnte und deshalb stufe ich es eher gefährlich ein, als wenn es einfach die gleiche Farbe hätte, aber nur diese Farbe. Und deshalb denke ich dass es eher als hoch eingestuft wird, nicht sehr hoch, weil es doch noch ein bisschen entfernt ist vom ganz Dunklen.

Beim zweiten Bild… Also ich schaue immer zuerst den grossen Ausschnitt an. Dort sehe ich eigentlich, dass es in der Nähe nirgends wirklich dunkelblau ist und deshalb stufe ich das eher so als geringer oder mittel einstufen. Und dann sehe ich noch den grösseren Ausschnitt an und sehe, dass es eigentlich gerade angrenzt an 0.1-0.5m Wasser und darum würde mich deshalb für sehr gering oder gering entscheiden… wobei wahrscheinlich eher… wahrscheinlich eher sehr gering, weil es am Rand ist.

Beim grossen Bild sehe ich wieder, dass es relativ in der Nähe bzw. also in dem rote Viereck…dass es noch angrenzt an Dunkelblau. Also 1.6-2.0m Wasser und darum würde ich eher zu hoch bis sehr hoch gehen. Wobei es allerdings im helleren Bereich ist und deshalb würde ich auf hoch tippen.

17

Also weil ich schon ein bisschen erfahren bin mit Wassertiefenkarten, bin ich mir gewöhnt als erstes immer zuerst die grosse Übersichtskarte anzuschauen. Und dann dort schauen, ob man dort ein grösseres oder kleineres Gewässer, grössere oder kleinere Gefährdung hat. Also ich meine, ob eine grössere Fläche mit hoher Fliesstiefen vorhanden ist. Und dann schaue ich den Gradient auf der grossen Karte an, in welche Fliesstiefe es fällt und wie gross der Gradient ist: Also wie schnell nimmt es auf der Seite zu mit der Fliesstiefen und je schneller der Gradient zunimmt, umso eine grössere Gefährdung nehme ich an. Das heisst, diese Fliesstiefenkarten sind schon genau, aber wenn es sehr stark zunimmt heisst das für mich, dass im Ereignisfall die höhere Fliesstiefe bis zum Haus kommen könnte… also es eine gewisse Ungenauigkeit gibt. Und darum, jetzt bei diesem Standort sehe ich, dass da sehr hohe Fliesstiefen sind und das Haus gerade direkt an der Grenze ist mit einer schnellen Zunahme der Fliesstiefen, deshalb würde ich da sehr hohe Gefährdung auswählen.

Beim zweiten Bild schaue ich auch zuerst die Übersichtskarte an. Ich sehe es ist eher flächiger, also die Gradienten sind nicht so gross und daher gehe ich zuerst davon aus, dass da geringere Gefährdungen sind. Da muss ich mich aber gleich selber korrigieren. Weil es sind eigentlich trotzdem relativ hohe Überflutungstiefen…bis zu 1m… beim ersten Anschein sieht es nicht nach viel aus, aber weil es flächig ist, täuscht das eigentlich. Deshalb ist es für mich immer noch eine sehr hohe Gefährdung.

Bei der dritten Aufgabe haben wir nochmals eine Intensität höher als vorher… also vorher hatte ich hoch… es ist halt immer relativ was man vorher geklickt hat. Man hat eine Fliesstiefe bis 1.5m, was sehr viel ist und das ganze Gebäude liegt in dieser Intensität drin und deshalb gehe ich dort gleich mal auf sehr hohes Risiko.

18

Ich habe noch oft auf den Kartenausschnitt geschaut und habe eigentlich am Anfang gedacht, diesen braucht man gar nicht, aber habe jetzt doch noch viel drauf geschaut. Da würde ich jetzt Mittel, weil da im hinteren Bereich mit 1.6-2.0m ziemlich nahe ist. Das wäre für mich ziemlich hoch… aber da es nur am Rand ist, mache ich jetzt Mittel.

Da ist es auf dem Kartenausschnitt sehr nahe an den eigentlich nur ganz tiefen 0.1-0.5 und am Rand zu 0.6-1.0m. Da würde ich jetzt gering und nicht sehr gering, weil es eben am Rand zu 0.6-1.0m ist.

Da hätte ich jetzt auch mittel gesagt, weil es in dem…hmm…muss kurz überlegen, was ich vorhin gemacht habe…maximal habe ich eigentlich nie angeklickt, weil es nie so ganz dunkel war…da klicke ich jetzt hoch, weil das ganze Haus im… 1.5m ist schon sehr hoch…, deshalb hoch.

19

Also das Haus ist ziemlich nahe an einem grossen Gewässer oder halt einer möglichen Überflutung, es ist so ein Grenzwert. Aber von der Vogelperspektive, also von dieser Sicht sieht man es nicht, aber auf der Karte sieht man es eindeutig. Deshalb würde ich hier sehr hoch bis maximal gehen. Ja… maximal.

Ja hier ist auch sehr viel rundherum. Aber es ist trotzdem noch auf einen sicheren Punkt. Ich würde hier mal hoch sagen.

Denn der letzte Abschnitt ist wahrscheinlich auch wieder an einem Gewässer, und deshalb auch schon höher…aber… ja schon sehr hoch, weil das Gewässer sich plötzlich noch mehr ausbreiten könnte, man weiss es ja nicht.

20

Also ich würde hier sagen, das ist in der Mitte, weil es auf dem Hellblauen, allerdings auch ein bisschen weiter unten und weiter oben. Deshalb würde ich das in die Mitte setzen.

Bei dem würde ich eher gering sagen, weil es zwischen 0.1 und 0.5m und zwischen 0.6 und 1.0m ist. Und weil ich vorher mittel angewählt habe und dieses ein bisschen weiter unten ist, würde ich das als gering anschauen.

Dann haben wir es hier ein bisschen tiefer. Das ist 1.1 bis 1.5m. Das ist ein bisschen…ich würde sagen, das ist hoch. Die anderen zwei wären ja noch dunkler.

21

Hier habe ich geschaut…es geht ja wie so ein bisschen rauf…also es sieht so aus, dass es eher in einem Hang liegt, darum habe ich mir gedacht, es kann eher abfliessen. Ich meinte ich habe mittel angeklickt. Das Wasser ist schon da, weil es doch relativ hoch ist und alles überschwemmt sein kann, aber ich habe die Hoffnung, dass das Wasser ein bisschen abfliessen kann… den Hang runter und deshalb habe ich Mittel genommen.

Hier habe ich gering genommen. Weil es hier nicht mehr so hoch ist und eigentlich sieht es auch so aus, als wäre es auf einem Hang. Aber weil es halt trotzdem in einem kleinen blauen Bereich ist…0.6-1.0m. Und eigentlich finde ich 0.1-0.5m nicht ein riesiges Risiko und ja… wenn man ein Haus bauen will.

Hier habe ich mir einfach gedacht, dass es aussieht, als wäre es gerade neben einen Fluss. Es hat wirklich viele Überschwemmungen dort unten und es sieht so aus, als wäre es in einer Tuele unten und vielleicht nicht gerade so allzuviel wie bei anderen Dunkelblauen, also so mitteldunkelblau… weiss nicht wie ich dem sagen soll… ja dort habe ich einfach hoch genommen.

22

Also zuerst schaue ich welche Farben betroffen sind, wo das Haus drauf steht. Es sind drei verschiedene Farben: Von der dritthöchsten Stufe bis die zweit-niedrigste Stufe sind betroffen. Und deshalb schätze ich es als mittel bis gering ein. Ähm… nein, ich stufe es als mittel ein. Ich schaue nachher noch kurz rechts und sehe das zwar rundherum ziemlich eine hohe Gefahrenstufe gibt… das dort vielleicht ein Fluss hindurchfliesst.

Beim nächsten Bild sehe ich, dass zwei verschiedene Farben betroffen sind: Die zweitniedrigste und drittniedrigste… ich klicke auf gering… wobei ich doch eher auf mittel tendiere. Weil es doch schon in der Mitte der Farbe ist und man sieht zwar rechts, auf dem grossem Bild, dass es recht sicher ist und kein Wasser kommt, aber links vielleicht irgendwo noch ein Fluss hindurchgeht oder so etwas.

Das letzte Bild zeigt eine ziemlich hohe Stufe… schon die dritthöchste Stufe auf der Karte und deshalb tippe ich hier auf hoch.

24

Ok… es ist ein bisschen überall Farbe. Aber es sieht nicht so aus, als wäre irgendwas irgendwie in Gefahr.

Hier ist es ziemlich hellblau. Da kann man sagen es ist gering… ja nein sogar sehr gering.

Hmm hier ist es ein bisschen dunkleres Blau, aber nicht ganz blau. Deshalb würde ich immer noch mittel sagen.

25

Hellblau mit wenig weiss… also klicke ich hier hoch.

Auch da ist auch hellblau… so ein bisschen ins Grau rein… also für mich auch noch hoch.

Und hier geht es ins Dunkelblau und rein von der Fläche, weil es eine grosse Fläche ist, ist es für mich sehr hoch.

26

Hier sieht man schon mal, dass das Haus zwischen zwei Farben ist. Zwischen 0.1-0.5m und 0.6-1.0m, das ist eigentlich fast eher bei den tieferen… also eher weniger Gefahr. Und rundherum… also ziemlich nahe kommen schon höhere Stufen, aber ich würde trotzdem sagen, dass es eine geringe Gefahr ist dort ein Haus zu bauen.

Und das Nächste ist ebenfalls zwischen zwei Farben. Zwischen 0.1-0.5m und 0.6-1.0m und rundherum sieht man eigentlich auch nichts, was gross tiefer ist und deshalb würde ich sagen, dass es eine sehr geringe Gefahr ist.

Beim Dritten ist das Haus eigentlich in der Tiefe von 1.1-1.5m, was eigentlich schon ein bisschen höher ist und nicht weit weg davon kann es schon 1.6-2.0m sein. Das heisst ich würde sagen dort ist es ein hohes Risiko.

27

Das war ein tricky Bild. Bei dem habe ich die Lagen angeschaut und habe gesehen, dass ziemlich viele Lagen in der Nähe sind…also es ist nicht eine Lage, sondern verschiedene Blautöne und es wird immer dunkler und deshalb habe ich mich bei dieser…so viel ich mich erinnern kann…mich für ein Risiko entschieden, welches hoch ist aus dem Grund, dass man eigentlich in einem Risikogebiet ist wo gering ist, aber durch die Gefahr, dass man sieht, dass es in der Nähe ist vom Dunkelblauen, habe ich mich dann für hoch entschieden.

Beim zweiten Bild habe ich gesehen, dass der grösste Teil sehr hell ist und darum bin ich zuerst mal auf minimal gegangen. Dann habe ich aber gesehen, dass noch ein bisschen ein dunkleres Blau da ist, aber das ist auch noch ein ziemliche Minimales…also bis 1.0m… und all 100 Jahre tritt es in Erscheinung und deshalb habe ich mich…so viel ich mich erinnern kann… für gering entschieden, weil es eben eine grosse Fläche sehr hell ist und die andere Fläche auch noch hell ist und nichts Dunkles dabei ist.

Beim letzten Bild habe ich mich…habe ich es mal angeschaut…also habe zuerst den kleinen Bildausschnitt angeschaut und habe gesehen, dass viel Dunkelblaues aussen herum ist. Ich glaube das sollte man nicht anschauen. Und dann habe ich nur das grosse Bild angeschaut und da habe ich gesehen, dass wir uns in einer mittleren bis hohen Risikogefahr befinden. Also dass dort eher ein bisschen ein höheres Wasser ist und darum die Chance grösser ist, dass es eine Überschwemmung geben kann… ja genau… und darum habe ich mich dort auch für hoch entschieden.

28

Hier denke ich, dass es eher im mittleren Bereich ist, weil es doch relativ nahe schon tiefes Wasser ist.

Hier weniger, aber trotzdem ein gewisses Risiko.

Hier schon ein bisschen mehr.

30

Hier würde ich es als sehr gering einschätzen, weil es so eher im hellblauen Bereich ist.

Auch hier würde ich wieder sehr gering sagen, weil…ja auch das Risiko eher klein ist bei so einer kleinen Wassermengen.

Hier würde ich eher ein bisschen höher auf gering gehen, weil es ein bisschen ins Dunklere geht.

31

Das ist jetzt zwischen zwei…eigentlich… es zeigt drei Farben an. Wegen dem habe ich das Gefühl es ist ein bisschen höher, obwohl es von 0.6 – 1.0m geht…also die Überflutung… aber für mich ist das ein Hoch und deshalb entscheide ich mich für hoch.

Hier geht es jetzt auch auf 2 Farben, die es berührt…aber hier gehe ich jetzt auf gering, weil…nein mittel, weil die andere Farbe ein bisschen dunkler ist. Wenn es jetzt noch heller wäre und näher zu Kein Wasser hätte ich gering genommen, aber so ist es für mich mittel.

Bei dem habe ich jetzt hoch, weil es umzingelt ist von einem dunklen Blau und das ist der Grund warum ich hier hoch anklicke.

32

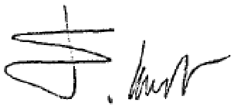
Also… bei dieser Karte habe ich jetzt v.a. überlegt, dass es ja v.a. in der Mitte ist… zwischen stark und eher… also ja zwischen tiefer Überflutung und eher weniger tief. Und wenn man auf die grosse Karte schaut, sieht man doch nebenan eigentlich ziemlich stark ist… also diese Fliesstiefe. Und darum habe ich es dort auch eher mittel bis hoch eingestuft, weil doch die Gefahr da ist, dass es doch ziemlich stark ist nebenan.

Dann beim nächsten ist es… ja die Fliesstiefe so 0.6 - 1.0m und es ist auch eher ein bisschen an der Grenze wieder, dass es eigentlich eher auch ein bisschen weniger sein könnte. Und ich meinte ich habe es dort eher so mittel eingestuft, weil…ja… es ist doch nicht so sehr stark aber trotzdem vorhanden.

Dann beim nächsten Bild ist das Haus ja in einer Zone wo die Fliesstiefe 1.1-1.5m beträgt und dort sind ja irgendwie auch sonst keine Häuser gebaut. Und es ist doch auch eher ein bisschen tiefer und wenn man auf die grosse Karte schaut, sieht man dass es dort verbunden ist mit einer noch tieferen Fliesstiefe und darum habe ich das eher hoch bis sehr hoch eingestuft.

Personal declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.



Fabian Kuster

Sursee, 28.01.2021