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Governance requirements for systemic risks: Lessons learned from the 2021 flooding in Germany

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Abstract

This thesis examines whether the 2021 flooding in Germany can be classified as a systemic risk, whether the previous governance approach has led to a worse crisis management and what improvements can be derived for systemic risk governance. The qualitative analysis was based on data from the Disaster Resilience for Extreme Climate Events (DIRECTED) project in the Erft region. The IRGC Guidelines for the Governance of Systemic Risks were used as a benchmark for an effective governance of systemic risks. The first research question, whether the 2021 flooding in the Erft valley was a systemic risk, was answered in the affirmative, as the event meets the definition of systemic risks and can be classified as a consequence of the systemic risk of climate change. The second research question, whether the previous governance approach has led to a worse crisis management, can also be answered in the affirmative. A fragmented governance approach was identified, leading to a lack of communication and data sharing and a worse crisis management. As part of the DIRECTED project, stakeholders are already working closely together to resolve these issues and it is recommended to continue this work to improve governance structures appropriate for systemic risk.

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1. Introduction

The flooding 2021 was the biggest disaster in regard to deaths in Germany since the 1962 flooding in Hamburg. At first it seemed unimaginable and unpredictable to the government. The high death rate let the government structures seem insufficient and the question arises whether the flooding can be defined as a systemic risk which raises the need for governance structures for systemic risks. This thesis will examine whether the flooding was a systemic risk and which improvements for governance requirements can be derived from the disaster.

Systemic risks pose major challenges to governments and societies as they are characterised by uncertainty, ambiguity, transboundary effects and non-linear cause-and-effect relationships with tipping points and are much more complex than conventional risks (Renn et al., 2022; P. Schweizer et al., 2022). Thereby, systemic risks require new governance frameworks, since existing frameworks are mostly only capable of dealing with conventional risks. To help organisations adapt to systemic risks, the International Risk Governance Center (IRGC) provides practical Guidelines for the Governance of Systemic Risks (IRGC, 2018). Climate change is such a systemic risk and is currently one of the most important challenges of the 21st century (Li et al., 2021). Anthropogenic global warming is continuously accelerated through ever-rising global greenhouse gas emissions (IPCC, 2023). Among other consequences, climate change is already affecting the frequency and intensity of weather and climate extremes, leading to severe loss and damage (Fekete & Sandholz, 2021; IPCC, 2023). Current research clearly states the increasing and severe impacts of weather extremes in the foreseeable future although detailed forecasts come with uncertainty (IPCC, 2023). An example of such an extreme weather event is the 2021 flooding in Germany. It posed major challenges for the government. The mismanagement of the crisis, in particular the lack of early warning, contributing to the deaths of 190 people was heavily criticised (Fekete & Sandholz, 2021; Thieken, Bubeck, et al., 2023; Thieken, Zenker, et al., 2023). This case is interesting to analyse as the extent and damage were devastating (Munich RE, 2022). Moreover, Germany as a federal country specifically faces challenges when it comes to governing systemic risks, since its fragmentation makes an inclusive systemic risk governing approach inherently more difficult. In this regard, the 2021 flooding is a useful example for further insights as it took place in multiple districts and several federal states.

Governing systemic risks is very important, as they will be a major challenge in the coming years in view of the increasing interconnectedness of the globalised world and the intensifying impact of climate change (Colon & Hochrainer-Stigler, 2023) and measures need to be further researched and implemented.

The present thesis explores if the 2021 flooding in Germany can be defined as a systemic risk and what lessons can be drawn from the crisis management of the flooding for systemic risk governance requirements. Based on this background the following research questions will be analysed in this thesis.

1. Was the 2021 flooding in the Erft valley a systemic risk?
2. Has the existing approach to risk governance in the case of the Erft valley led to *worse crisis managemen*t of the flood disaster compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
    2.1. Has the existing approach to risk governance led to *poorer communication* between involved stakeholders compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
    2.2. Has the existing approach to risk governance led to *poorer information sharing* from the stakeholders' perspective compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?

This thesis seeks to expand existing insights of the 2021 flooding in Germany, specifically by investigating issues of mismanagement and identifying concrete points for improvements and suitable governance structures for dealing with systemic risks. These case specific findings can then be generalised and applied to other cases. Thereby, this thesis complements the science of systemic risks and its governance requirements which is still in its early stages (United Nations Office for Disaster Risk Reduction, 2022).

First, in the literature review characteristics of systemic risks, climate change as a systemic risk, and details of the 2021 flooding event will be summarised. Afterwards, the IRGC Guidelines for the Governance of Systemic Risks will be explained and used as a basis for the operationalisation and analysis. This is followed by the analysis and discussion of the research questions and concluded with a recommendation section.

2. Literature review

In the following paragraphs, the current state of research on systemic risks, climate change as a systemic risk and the 2021 flooding in Germany will be summarised.

2.1 Systemic risks

Systemic risks distinguish themselves from conventional risks. Although the difference is not clearly binary and corresponds more to a continuum, there are criteria that define a risk as conventional or systemic (P. Schweizer et al., 2022). Conventional risks are defined by linear cause-effect relationships and are enclosed in space and time. In contrast, systemic risks are highly complex and characterised by uncertainty, ambiguity, transboundary effects, stochastic and non-linear cause-and-effect relationships with tipping points (Renn et al., 2022; P. Schweizer et al., 2022). As a result of these characteristics, individual failures, incidents or disruptions threaten the whole system through the process of contagion (IRGC, 2018). Thereby, the term systemic risk refers to the risk or probability of the collapse of an entire system rather than collapse of individual components (Kaufman & Scott, 2003).

The *high complexity* of systemic risks occurs due to the following factors. Systemic risks are highly dependent on the specific context and are related to cascading effects within and outside the original domain of risk (Renn et al., 2022). Moreover, systemic risks are risks that are highly interconnected in an interdependent environment and there is a lack of knowledge about these connections (IRGC, 2018). Thereby, it is difficult to identify and quantify causal links between different factors and events. Identifying triggers and causal relationships is also challenging, as all elements interact within feedback loops and have delayed effects (Lucas et al., 2018). Because of these characteristics, the term of nonlinear response functions is often used for systemic risks. The multitude of factors complicate scientific investigations on the cause-effect-relationship and underline the complexity of systemic risks.

Caused by this complexity, systemic risks are characterised by *high uncertainty*. The interaction and reinforcement between different factors result in an unusual high level of uncertainty which cannot be measured within common statistical confidence intervals (P. Schweizer et al., 2022). Moreover, the described dependency on the context can lead to different outcomes of same triggers depending on the starting situation. Thus, the formulation of a general effect of a factor is impeded. This leads to difficulties determining and forecasting specific magnitudes and probabilities of certain events (P. Schweizer et al., 2022).

In addition to the described uncertainty, scientific results and forecasts on systemic risks pose the challenge that there is *ambiguity* when it comes to interpreting the results. The data itself is often agreed upon by experts. However, there is a variety of opinions which implications can be drawn from the same data and observations. This is due to different interpretations of statements and different normative rules to assess situations and results. This ambiguity of interpreting data is exacerbated by the described high complexity and uncertainty of systemic risks (Renn et al., 2022).

Furthermore, systemic risks are shaped by *transboundary effects*. A certain risk might have its origin in a specific domain, but a triggered effect chain might ripple through other systems with a greater or lesser impact (Aven & Renn, 2020). These cascading effects do not stop at geographical or sectoral boundaries. Transboundary effects also contribute to the complexity of systemic risks and the difficulties of identifying the trigger or cause of an impact. An example of a systemic risk was the COVID-19 pandemic. At first only the health sector was affected but soon the global financial markets suffered under the severe impacts of the virus pandemic (Zhang et al., 2020).

Finally, systemic risks are described by *stochastic and non-linear cause-and-effect relationships* with *tipping points*. Systemic risks follow a non-linear cause and effect chain which cannot be defined in a deterministic and mono-causal manner (P.-J. Schweizer, 2019). Although this makes more it difficult to identify original trigger and its causes, it is still possible to identify causal parameters and a spectrum of potential results which are not arbitrary (P.-J. Schweizer, 2019). This is exacerbated by the high interconnectedness of causal structures (Renn et al., 2022). Not only can the cause of a certain effect appear in another section but also with a timely delay, i.e. one can identify a non-linear relationship. Furthermore, the calculation of the probability of a certain event is always subject to uncertainty, hence the stochastic relationship. In addition, tipping points shape the non-linear relationship. If a certain threshold is exceeded, a cascading effect starts and it cannot be reversed or stopped by any behaviour or action (P. Schweizer et al., 2022). In addition, feedback loops are part of non-linear cause-effect relationships, as some effects spill over to multiple systems and then feed back to the original system, creating a loop (IRGC, 2018).

These differences between conventional and systemic risks signify highlight the need of different governance methods to deal with them. Conventional risks underly little uncertainty and ambiguity and effective conventional risk management and governance tools are well known, even if they are not always implemented in practice (P. Schweizer et al., 2022). On the contrary, there is a lack of knowledge about how to govern systemic risks. This is due to their complexity and interconnectedness, a sectoral policy tradition, a deficit of management knowledge and communication of the importance of systemic risks to policy makers (P. Schweizer et al., 2022). In the context of systemic risks, sectoral policies are insufficient as systemic risks ripple through different systems and thereby cross national and sectoral boundaries and responsibilities (P. Schweizer et al., 2022). But not only complexity challenges an effective systemic risk governance, also uncertainty and ambiguity. Uncertainty arises since a potential systemic risk can only be stated with a statistical probability and since systemic risks are always tightly coupled with social systems, wherein human behaviour is difficult predetermine (P.-J. Schweizer, 2019). Moreover, ambiguity arises due to different interpretations of data and different normative assumptions (e.g. moral principles), leading to diverging opinions which concrete measure and risk management options should be chosen (P.-J. Schweizer, 2019). There are different ideas to deal with systemic risks. One approach is *multilevel governance* (Hooghe & Marks, 2003, 2010), in which the decision-making process is decentralised and powers are distributed among various actors. Accordingly, scientists emphasise that systemic risks caused by climate change require transformations on multi-levels like niches, regimes, and landscapes. This transition can be supported and upscaled from governments by using innovation and industrial policy (IRGC, 2018). However, this process can only be successful if many actors within society are involved and not only the government. Through *inclusive risk governance* this goal of broader involvement can be achieved. Inclusive risk governance entails involving various stakeholders (governmental and private actors) and leads to an improved and transparent decision-making process concerning risk issues (P.-J. Schweizer, 2019; P.-J. Schweizer & Renn, 2019). Through deliberative processes, this form of risk governance embraces a plurality of knowledge, values and cultural patterns, shares power between different actors and collectively defines goals. Although there are these governance approaches to deal with and mitigate systemic risks, there are still shortcomings in understanding the dynamics and assessing and governing systemic risk.

2.2 Climate change as a systemic risk

Climate change is one of the biggest challenges and threats facing humanity in the 21st century. The main cause of global warming is the increase in the concentration of CO_2 in the atmosphere from 280 parts per million in 1750 (Nordhaus, 2019) to 415 parts per million in 2021 (IPCC, 2023). This is mainly due to the burning of fossil fuels for energy production since the industrial revolution (IPCC, 2021). Moreover, land-use-changes like deforestation and consumption patterns increase global greenhouse gas concentration as well. According to the IPCC (2021), global mean temperatures and cumulative CO_2 emissions are correlated. The global average surface temperature in the period 2011-2020 is 1.1 °C higher than in the period 1850-1900 (IPCC, 2023). These research results show that climate change is unequivocally human-made and although there are mitigation efforts for example by the Paris Agreement, global greenhouse gas emissions continue to rise (IPCC, 2023). According to Nordhaus (2019), CO_2 concentrations will reach 700-900 ppm by 2100, resulting in 3-5°C of warming if no strong mitigation action is taken. The speed of climate change will have severe impacts on nature and represents currently one of the greatest threats to humankind (Deere-Birbeck, 2009; Li et al., 2021). Global warming leads to massive changes in the biosphere, cryosphere, atmosphere and oceans, leading to sea level rise and more frequent and intense extreme weather events like heatwaves and heavy precipitation globally (Fekete & Sandholz, 2021; IPCC, 2023). Water cycles will change, leading to more frequent and more intense heavy precipitation over land (IPCC, 2021). As a result, climate change causes economic damage in multiple sectors such as agriculture, fisheries, energy, forestry and tourism, as well as human livelihoods being threatened through the destruction of buildings, loss of income, food insecurity and health issues (IPCC, 2023). In this context, it is important to mention that human vulnerability is enhanced by inequity and marginalisation such as income inequality, gender-bias, racism, ageism and colonialism (IPCC, 2023). This is in line with results of the World Bank (2010), stating that developing countries will be more threatened by global warming because they are exposed to greater local risks and have fewer opportunities to adapt.

Framing climate change as a systemic risk results from the interaction of the harmful impacts of a changing climate, the growing complexity of the connections with and within the socio-economic systems and the continuous changes in terms of how strongly and which population groups and regions are affected (Li et al., 2021). A combination of specific single risks can become a systemic risk through interactions and chain effects with tipping points. An example of an interconnected single risk linked to multiple other risks is the low water level of the Rhine in 2018, which led to massive constraints on the transport of industrial goods, interrupted supply chains, and reduced economic output by around 0.4% for the whole of Germany (Kaufmann, 2023), a locally disrupted water supply (Niehues & Merkel, 2020), a decline in agricultural production and increased water temperatures with associated environmental disruption (Schwandt, 2018). Although a continuous increase in greenhouse gas concentrations acts at the beginning of the causal chain, there is a wide range of possible impacts, which can occur very selectively, very violently and are difficult to predict or unpredictable (Li et al., 2021). Climate change as a systemic risk therefore has a massive impact on the well-being of the world's population and the underlying structures upon which this well-being is based.

In the case of climate change as a systemic risk, there are three core factors: the areas affected by the damage, the severity of the damage and the probability of the damage occurring. Especially the areas of economy, society, security, human health and living conditions should be considered when it comes to the damage caused by the consequences of climate change (Li et al., 2021). It must be also taken into account that, beyond continuous developments, systemic risks induced by climate change can hardly or no longer be managed once threshold values have been exceeded (Li et al., 2021). The interaction between climate change and complex human systems such as financial systems poses one of the greatest climate risks (Li et al., 2021).

2.3 2021 Flooding in Germany

From 12 to 19 July 2021, the atmospheric low-pressure system “Bernd” caused intense rainfall in Western and central Europe, leading to severe floodings in Belgium, Germany, Luxembourg and the Netherlands (Kron et al., 2022; Schneider & Gebauer, 2021). In Germany, the two *Bundesländer* (federal states) North Rhine Westphalia (NRW) and Rhineland-Palatinate (RLP) were particularly affected with more than 100 litres/m² of precipitation in 72 hours in large parts of the region (Junghänel et al., 2021). Local maxima with even more than 150 litres/m² of precipitation within 24 hours were recorded (Junghänel et al., 2021). In addition, the ground in the heavy rainfall areas was already very wet, meaning that the retention capacity of the soil was exhausted. This resulted in rapidly rising flash floods, particularly in the mostly steep and narrow river valleys of the Eifel mountains in Rhineland-Palatinate and North Rhine-Westphalia (Kron et al., 2022). The flooding caused 190 deaths in Germany, making it the flood disaster with the most fatalities in Germany since the flooding on the North Sea coast in 1962 (Thieken, Zenker, et al., 2023). Of these 190 people, 49 died in the federal state of North Rhine-Westphalia and 136 in the neighbouring federal state of Rhineland-Palatinate (Fekete & Sandholz, 2021; Thieken, Bubeck, et al., 2023; Thieken, Zenker, et al., 2023). Although the region had already been hit by similarly heavy rainfall in 1804 and 1910, it did seem to be insufficiently prepared for such an event (Roggenkamp & Herget, 2014). The considerable economic damage is estimated at 33 billion euros, making it the most expensive natural hazard in Germany to date (Munich RE, 2022). Public infrastructure as well as residential, commercial and industrial sectors were affected (Munich RE, 2022). While the economic damage was dramatic and would have been difficult to prevent in the short term, many fatalities could have been avoided by timely warnings and evacuation. Although it was difficult to accurately forecast the water levels and the actual gauge levels turned out to be higher than predicted (Kron et al., 2022), the potential of an extraordinary high precipitation event for the affected area were predicted more than 2 days before the flooding (Mohr et al., 2023). Warning level 4 of the German Weather Service (DWD) was also issued in time, but the urgency of the information was partially lost on the way to stakeholders and individuals. (Kron et al., 2022). In line with this information, investigations criticised a lack of warning and bad crisis and risk communication leading to underestimation and insufficient awareness (Schopp et al., 2023; Thieken, Zenker, et al., 2023). A survey showed that the information provided to the population was inadequate, 35% of the affected respondents in NRW received no warning at all and of those who did receive a warning, 85% did not expect very severe flooding (Thieken, Bubeck, et al., 2023). In addition to the lack of early warning, individual misconduct and inadequate preparation for behaviour in such an event were criticised (Kron et al., 2022). Meteorological warnings must be accompanied by information about the specific consequences and concrete instructions so that residents can act appropriately (Kron et al., 2022).

In addition to the already saturated soil and the heavy rain, there were other factors that contributed to a disaster of this magnitude in the mostly steep and narrow valleys of Ahr, Erft, Rur, Kyll, Prüm, Wupper and Ruhr rivers. Firstly, the slate rock typical of the Eifel meant that the water was unable to seep away (Kron et al., 2022). On top of that, the river valleys are densely built-up and the slopes of the valleys are often covered with vineyards (Kron et al., 2022). This combination ensured that the accumulated precipitation quickly ran off the slopes into the valley, where it was unable to drain away properly due to the dense construction (Kron et al., 2022). Especially the density of construction like buildings and bridges have changed in the last 100 years leading to higher flow resistance than in previous flood disasters in 1804 and 1910 (Kron et al., 2022). Moreover, the regions affected by the rainfall had different levels of precautionary measures against flood disasters. While some affected areas, such as the Rur catchment, were effectively protected by several dams and major damage could be prevented, this was not the case in the Ahr and Erft areas (Kron et al., 2022). The Ahr and Erft areas had only small retention areas which have been insufficient for flash floods of this size (Kron et al., 2022). This combination of geographic features, lack of retention areas, densely built-up and sealed surfaces as well as wet soil and enormous rainfall were the main causes of the huge flooding (Kron et al., 2022).

The flood had a massive impact on the region and its inhabitants. Nearly all streams, rivers and tributaries overspilled and flash floods caused massive erosion and undermining of slopes, roads, railway lines and buildings, and trees fell down (Kron et al., 2022). One example of the severe erosion caused by the flood is the collapse and undermining of 8 houses in Erftstadt-Blessem. Here, the Erft flooded a gravel pack and caused the destruction of the buildings through backward erosion. Besides many buildings, important parts of critical infrastructure were built in areas that were severely affected by the flood. The flood damaged sewage treatment plants, gas, water and electricity networks. The water quality was affected by damage to oil tanks and pipes and the *Wasserwerke Westfalen* had to shut down one of its plants (TAZ, 2021). As a result, 165,000 people in NRW and RLP were left without electricity and mobile phones immediately after the flood and the drinking water supply collapsed in some areas (Kron et al., 2022). As part of the critical infrastructure, hospitals and medical practices were affected by the flood. The fact that the critical equipment in hospitals is often located in the basement exacerbated the problems within the flooded hospitals. In the town of Eschweiler, the flood led to a complete power failure, meaning that 300 patients had to be evacuated through stairwells, exposing them to further risk (Kron et al., 2022). More than 100 medical practices in Nordrhein were unable to work, 25 of them in the district of Euskirchen (ÄrzteZeitung, 2021a). In addition, the medical care situation was exacerbated by a lack of antibiotics, infusions, disinfectants and urgently needed medicines (Thomas, 2021). Furthermore, according to the doctors, the health insurance companies did not correctly assess the severity of the situation, which meant that many doctors did not prescribe expensive medication because they were afraid of having to pay the health insurance companies back. (Thomas, 2021). The limited medical care, the progressive decomposition of corpses and animal carcasses and working in rubble and infectious mud also led to a temporarily increased risk of epidemics and infections (Büchs, 2021; Gries, 2021; Thomas, 2021). At the end of August, the risk of an epidemic was officially denied (ÄrzteZeitung, 2021b).

The destruction of the transport infrastructure played a key role in the disaster. The destruction of bridges and streets exacerbated the situation massively, as the population was cut off from important infrastructure such as hospitals, fire stations, rescue centres and the police. The railway infrastructure was also severely damaged (Kron et al., 2022). Over time, bridges were blocked by floating debris, wood and trees causing the water level to rise further even without additional rainfall (Kron et al., 2022).

Moreover, the public administration staff was personally affected by the flooding, so they could not help the citizens as much as needed (Kron et al., 2022). In line with this, an investigation by Nick et al. (2023) showed a lack of experts and authorities on site as they were personally affected. As another consequence of the flooding, public order could not be maintained and looting occurred (SPIEGEL, 2021). Overall, Nick et al. (2023) stated that bureaucratic structures impeded communication, collaboration and coordination.

Initially, the flood was perceived as unpredictable and unprecedented. In the collective memory of the locals, the floods of previous decades served as a benchmark. In fact, there were similarly severe flood disasters in the region in 1910 and 1804

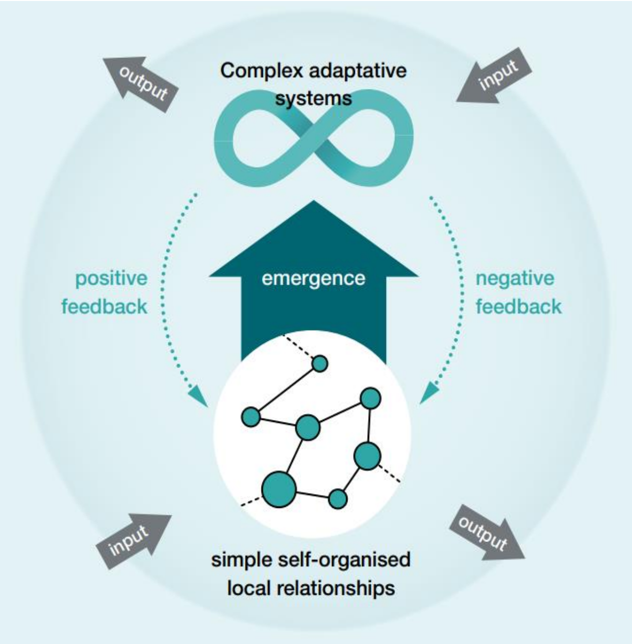
(Roggenkamp & Herget, 2014). Although a flood of this magnitude has long been considered a centennial event for a long time, a recent attribution study suggests that human-induced climate change is increasing the severity and likelihood of such extreme weather events. Tradowsky et al. (2023) estimate that the current global warming of 1.2°C has increased the likelihood of such an extreme rainfall event in western Europe by a factor of 1.2 to 9. If global warming continues, the frequency of such events will increase even further. In addition, 39 researchers from the World Weather Attribution Initiative state that anthropogenic climate change has increased the intensity of precipitation in the region by between 3% and 19% (World Weather Attribution, 2021).

3. Theory: IRGC Guidelines for the Governance of Systemic Risks

This chapter refers entirely to the report *IRGC Guidelines for the Governance of Systemic Risks* published by the International Risk Governance Center (IRGC, 2018). Through globalisation and climate change impacts our world is becoming more interconnected, increasing the threat of systemic risk. Systemic risks evolve due to dynamic complex adaptive systems with distributed interacting components that are influenced by internal and external factors, which can lead to disruptions or collapse. Therefore, systemic risk governance is required to deal with systemic risks. This involves supporting and strengthening the system's ability to organise and control itself. To this end, proactive measures must be taken to prevent, mitigate, adapt and transform systemic risks. At the same time, precautions must be taken in the event of disasters and crises. With its guidelines, the report aims to help organisations deal with systemic risks by describing basic principles and concepts for their governance requirements.

Figure 1

Complex adaptive system in a changing external environment



Note: From IRGC Guidelines for the Governance of Systemic Risks (p. 10), by IRGC, 2018, International Risk Governance Center. Copyright by EPFL International Risk Governance Center 2018

Complex adaptive systems can significantly increase system effectiveness and service quality through their internal and external relationships. However, this can lead to a reduction in resilience to disruptions if buffer capacities are not provided and if the connections between system elements are too rigid and without alternatives. Such problems become apparent, for example, when supply chains are affected. The more interconnected systems are, the higher the systemic risks become. Therefore, the OECD recommends that governments should endeavour to focus on chain reactions with global consequences, strengthen resilience and create capacities for improved mobility in order to be prepared in the event of risks.

The transformation and management of systemic risks is hindered by various effects. Due to their complexity, systemic risks are intuitively underestimated. Parties with vested interests take advantage of this intuitive underestimation. In every change process, there are parties with vested interests that stand in the way of the overarching goal. For example, the oil industry is putting up considerable resistance to the system change from fossil fuels to renewable energies, also by influencing public opinion (Geels, 2014). Such effects must be considered and it shows that the complexity is not only on the scientific side, but also in the interaction of socio-technical systems. Moreover, complexity is not the only difficulty for human perception, non-linear relationships and tipping points also pose major challenges for people, as they tend to learn by trial and error. Another problem in managing systemic risk is the distribution of responsibility across different parts of the system and the fact that no one is legitimised and capable to influence the entire system. In this context, the common pool problem applies to systemic risks, as everyone involved benefits from the free rider position in the short term without investing in risk mitigation. Therefore, systemic risk governance should take into account the totality of actors, rules, conventions, processes and mechanisms involved in collecting, analysing and communicating relevant information. To date the political and economic systems are not prepared to process such complex information. The transition from systemic risks must therefore be developed in the form of principles and instruments and made operationalisable. For example, time periods must be considered that extend further into the future than the usual planning horizons. Not only the prevention of undesirable developments, but also the mitigation of negative effects, the limitation of collapses or the transformation into new systems, e.g. through the strengthening of crosscutting issues or the involvement of experts, can be helpful. In complex Western democracies, it is important that the population is involved in the decision-making process. Thorough preparation is needed to build political capital for a paradigm shift in dealing with systemic threats. The proposed *Guidelines for the Governance of Systemic Risks* comprise seven interlinked steps with possible iterations between and within steps. It is also possible to start at various entry points depending on the situation. A *process manager* liaises between the various stakeholders, navigates the transition and ensures the effective implementation of the entire process. *Communication*, *openness* and *transparency* are central to each step. An overview of all seven steps is displayed at figure 2. In the following, all seven steps are described and summarised according to the IRGC (2018).

Figure 2

Elements of IRGC's Systemic Risks Governance Guidelines

Note: From IRGC Guidelines for the Governance of Systemic Risks (p. 19), by IRGC, 2018, International Risk Governance Center. Copyright by EPFL International Risk Governance Center 2018

Step 1 is to explore the system in which the organisation operates and to define its boundaries and dynamics. The aim is to gain an overview of the system. The environment is just as important as internal processes, the interaction between internal and external processes and the direction in which the system is moving. Of particular importance are scanning and analysing the organisation's internal and external environment and boundaries, the position of the organisation and interconnectedness with other systems, the institutional capacity for analysing the environment, the communication and collaboration with others, the scientific approach to data collection and environment scanning for early warning signals.

Step 2 is to develop possible scenarios whereby internal and external levers that influence the system are analysed. By developing and analysing the emergence of alternative futures which might be unlikely, potential threats become visible. The developed scenarios are not used to quantify the possibility of the occurrence of certain events but to review how the system reacts and performs in different situations. Thereby, the understanding of the system can be deepened, its interconnectedness to other systems can be identified and its ability to function can be tested. Thus, the application of this step does not only include foresight (forward-looking scenarios) but also broadsight which means to investigate interconnected systems horizontally (Tourki et al., 2013).

Step 3 is to determine goals and level of tolerability for risk and uncertainty. On basis of the results of the system analysis and possible scenarios, short, medium and long-term goals are defined. It can also be differentiated between business goals and normative goals, e.g. improving sustainability, achieving more inclusive economic growth. In addition, the tolerability for risk and uncertainty should be defined as they influence the design of the objectives.

Step 4 is to co-develop management strategies to address scenarios from step 2 and to navigate the transition. The collaboration with various stakeholders and the involvement of external bodies is crucial for this step. The goal is to increase resilience to systemic risks and to encourage self-organisation. The strategies are based on the scenarios from step 2 and aim to prevent, mitigate, adapt and transform systemic risks. The management strategies should also prepare for disruptions, accidents and crises. As it is not possible to anticipate all eventualities, the strategies must remain flexible and capable of development.

Step 5 is to address unanticipated barriers and sudden critical shifts. In complex adaptive systems, chain reactions can lead to unexpected obstacles despite all precautions. Therefore, deliberative exercises should be conducted to identify and overcome barriers and everyone involved should be prepared and legitimised to overcome barriers. Transparency, agility and openness to innovation are important for overcoming blockades. If unexpected barriers occur, steps 1-4 can be skipped in the event of a crisis.

Step 6 is to decide, test and implement strategies. After deciding on the most suitable strategy, a test run should be carried out before implementation if possible. Realisations in sub-areas or virtual simulations can provide valuable information for the design of the final strategy. The decision-making process should be based on clear and transparent decision-making criteria and involve all relevant stakeholders.

Step 7 is to monitor, to learn from strategy implementation and to review and adapt. The implemented strategy should be regularly scrutinised and reviewed in light of the evaluation of strategic decisions and new findings. Increasing resilience is an important aspect of this. Capacity must be made available for any necessary adjustments to the strategy. It is crucial that the strategy remains flexible through adjustment loops, iterative processes and learning from experience.

4. Methodology

The following subsections explain the scientific basis on which the case study was chosen, and which data will be analysed. Furthermore, the choice of analytical methods and operationalisation will be elaborated.

4.1 Case selection

In order to gain more in-depth insights into the requirements of systemic risks and how existing governance approaches can be improved to deal with systemic risks, concrete objects of investigation must be selected. To receive meaningful qualitative in-depth conclusions with an appropriate scope a statistical analysis is unsuitable. In contrast, the aim of a case study is an analytical generalisation (Rowley, 2002). A case study does not represent a method but a research strategy which is useful to analyse an object holistically and embedded in a specific context (Patton & Appelbaum, 2003; Rowley, 2002). Thereby, a case study is an appropriate strategy to analyse governance requirements for systemic risks as they need to be investigated within a real-life context.

Since the sample of huge disasters is relatively small in Germany, a random selection of cases is not suitable, as a random sample is very unreliable for small N of research samples (Seawright & Gerring, 2008). Therefore, a non-randomised case selection is used. When applying a non-randomised case selection, it is important to avoid systemic bias and to select cases in an information-orientated and theory-driven way that ensures that detailed individual case selection maximises utility. One commonly used method is to select a typical case (Seawright & Gerring, 2008). A typical case is defined as a typical example of a specific event and it represents a typical cross-case relationship. Due to this definition, the typical case is representative. The aim of this method is to investigate causal mechanisms that either confirm or disprove a particular theory. Given the small number of potential cases and the availability of information, this paper examines data from the Disaster Resilience for Extreme Climate Events (DIRECTED) project of (among other partners) the RIFS (Research Institute for Sustainability - Helmholtz Centre Potsdam) which deals with the disaster management and climate change adaption strategy of the Rhine-Erft region. The 2021 flooding in Germany caused 190 deaths, making it the worst flood disaster since 1962 in Germany (Thieken, Zenker, et al., 2023). The two Bundesländer (federal states) North Rhine-Westphalia (49 deaths) and neighbouring Rhineland-Palatinate (136 deaths) were particularly affected (Fekete &

Sandholz, 2021; Thieken, Zenker, et al., 2023). Because of the magnitude of this disaster, it is important to analyse causes and potential improvements in governance structures.

The disaster can be categorised as a typical disaster case due to the following characteristics. The flooding was caused by heavy rainfall which was precisely forecasted only a few hours before the event, which is typical for heavy rainfall events. The flood caused massive economic damage and fatalities. Recent investigations have criticised a lack of warning and poor crisis and risk communication, leading to underestimation and insufficient awareness (Schopp et al., 2023; Thieken, Zenker, et al., 2023). As a result, this case lends itself to further analysis of concrete governance failures and possible improvements for the future. The situation of the affected areas in North Rhine-Westphalia and Rhineland-Palatinate is typical for the whole of Germany, as every region in Germany is characterised by a fragmented administration and shared responsibilities between federal states and the Federation. In times of peace the federal states (e.g. NRW) are in charge of the *disaster management* ("Katastrophenschutz"), whereas the Federation is responsible for *civil protection* ("Zivilschutz") in the case of defence (European Commission, 2021). The Federation provides disaster assistance to the federal states upon request (Bundesministerium des Innern und für Heimat, 2024; European Commission, 2021). This bureaucratic and divided structure can lead to difficulties if a disaster concerns neighboured regions in different federal states as in this case in NRW and RLP. There is also a further division of responsibilities, as in the event of a disaster, the municipalities and districts are responsible for protecting local citizens as the lower disaster control authorities (Bundesministerium des Innern und für Heimat, 2024). Due to these characteristics, the 2021 flood is an interesting typical case to study the governance of systemic risks in detail and to generalise to other cases in Germany. As stated in the literature review above, the governance of systemic risk requires a holistic, inclusive and interdependently connected approach. Due to its size, the 2021 flooding in Germany was affecting multiple districts and responsible actors.

4.2 Data and methodologies: Qualitative analysis

A qualitative approach is applied to gain in-depth insights into the governance requirements for systemic risks based on the case study of the 2021 flooding in Germany. Data from the DIRECTED project will be qualitatively analysed. The EU-funded DIRECTED project aims to reduce vulnerability to extreme weather events and to promote the disaster resilience of European societies by fostering interoperable data, communication and governance between all stakeholders of disaster risk management (Directed Project, 2022). For their work, the project uses different Real-World Labs to analyse and improve current governance related to disaster risk management. One of these Real-World Labs is the Rhine-Erft region led by the Erftverband which includes the districts of Euskirchen and Rhein-Erft with 21 municipalities in total. In the aftermath of the 2021 flooding the DIRECTED team initialised meetings with several affected stakeholders of the region and conducted a survey with the two districts Euskirchen and Rhein-Erft to improve existing communication pathways and to co-develop an integrated risk-management strategy. These documents from the stakeholder meetings and the surveys are the data that will be analysed. In the following, the participants of the stakeholder meetings and surveys are pseudonymised as stakeholder 1 (SH1), stakeholder 2 (SH2) and stakeholder 3 (SH3). The author of this thesis was working as an intern at RIFS to get access to these documents.

4.3 Operationalisation

To answer the following research questions, the results of the stakeholder workshops and surveys will be qualitatively analysed.

1. Was the 2021 flooding in the Erft valley a systemic risk?
2. Has the existing approach to risk governance in the case of the Erft valley led to *worse crisis managemen*t of the flood disaster compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.1. Has the existing approach to risk governance led to *poorer communication* between involved stakeholders compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.2. Has the existing approach to risk governance led to *poorer information sharing* from the stakeholders' perspective compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?

For the qualitative analysis of the governance structures in the Erft valley, the Guidelines for the Governance of Systemic Risks are used as a benchmark and indicator for an effective and good governance of systemic risks (IRGC, 2018). The aim is to identify consistent and inconsistent statements in the documents with the aspects of the IRGC Guidelines for the Governance of Systemic Risks. For conducting a qualitative analysis, a pre-structuring of categories is a central element. The IRGC guidelines contain 7 steps that are carried out with iterations within and between steps and if necessary certain steps can be skipped. There is also a reference to previous steps after the 7th step (monitoring). Thus, the guideline represents a recurring cycle of instructions. Key elements in all described phases of the process are communication, openness and transparency. As the IRGC guidelines are extensive and complex, it is shortened to those aspects that appear important to the flooding. In order to operationalise the content, table 1 displays elaborated single criteria for each step conducted by the author of the present thesis. They will be used to identify effective governance of systemic risks.

Table 1

IRGC Steps with extracted single criteria

IRGC Steps	Short description of the step	Single criteria
Step 1	Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment.	Scanning and analysing the organisation's internal environment and boundaries
		Scanning and analysing the organisation's external environment and boundaries
		Position of the organisation and interconnectedness with other systems
		Institutional capacities for analysing the environment
		Communication and collaboration with others (diversity of information)
		Scientific approach to data collection, analysis and priorisation
		Environment scanning for weak / early warning signals
Step 2	Develop scenarios, considering ongoing and potential future transitions.	Develop scenarios of future developments (alternative futures), including low probability scenarios
		Potential future transitions
Step 3	Determine goals and the level of tolerability for risk and uncertainty.	Short-, medium- and long-term goals
		Business or economic goals
		Normative goals
		Tolerability for risk and uncertainty
Step 4	Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition.	Co-develop solutions with other actors
		Build resilience – encourage self-organisation
		Prepare for disruptions, accidents, crises
		Address scenarios from step 2 (with a list of management strategies)

IRGC Steps	Short description of the step	Single criteria
Step 5	Address unanticipated barriers and sudden critical shifts that may come up during the process.	deliberative exercises to identify and overcome barriers
		All involved stakeholders prepared and legitimised to overcome barriers
		Transparency, agility, openness to innovation (to overcome barriers)
Step 6	Decide, test and implement strategies.	Compare the strategy options developed in steps 4 and 5
		Test and experiment strategies
		decide which strategies to implement
		Clear and transparent decision-making criteria
		Involve all stakeholders in decision-making
Step 7	Monitor, learn from implementation, review and adapt.	Regular monitoring of the strategies
		Learn from implementation
		Review and adapt
		Flexibility through adjustment loops and iterative processes

5. Analysis

In the following sections each research question will be consecutively examined. In order to answer the first research question, whether the 2021 flooding represents a systemic risk, existing literature on systemic risks and the flooding as well as available materials from the DIRECTED project are used. The first question is therefore about the nature of systemic risks and whether they exist in the case of the flood. As the climate crisis has already been categorised as a systemic risk in the literature, this analysis focuses on whether the specific flood itself can be classified as a systemic risk. These two aspects are linked by the results of the attribution study (Tradowsky et al., 2023). To analyse the second research question and its two subquestions, the IRGC guidelines are used to determine whether the existing governance structure has led to poorer crisis management.

5.1 Was the 2021 flooding in the Erft valley a systemic risk?

The present section analyses and deductively argues on the basis of existing literature and available DIRECTED documents whether the 2021 flooding in the Erft valley can be defined as a systemic risk. As described in the literature review, systemic risks are characterised by five distinctive features: Complexity, uncertainty, ambiguity, transboundary effects and stochastic and non-linear relationships with tipping points.

Complexity lies in the fact that the disaster was influenced by different levels, which are themselves characterised by a high degree of complexity. Despite all modern forecasting methods, the early warning of heavy precipitation is often not precise due to complex influencing factors. Rain bursts are often caused by dynamic convective storm cells which appear locally. This results in difficulties to predict accurate values for time, location and intensity of heavy precipitation (Kron et al., 2022). Due to this complexity a locally more precise forecast of heavy rain can often only be made a few hours before the event occurs. This was also the case for the 2021 flooding. Although the potential of an extraordinary high precipitation event for the affected area was predicted 2 days before the disaster, precise forecasts have been only available a few hours in advance (Ludwig et al., 2023). As typical for a systemic risk and its complexity, the disaster was highly dependent on the specific context. The amount of rainfall only led to such a dramatic flooding due to additional contextual factors such as already wet soil, steep river valleys, lack of retention areas and densely built-up and sealed surfaces (Kron et al., 2022). In addition to the complexity of weather extremes themselves, the organisational structures and communication pathways are complex. Each federal state is separately in charge of the disaster management with municipalities and districts as lower disaster risks authorities (Bundesministerium des Innern und für Heimat, 2024; European Commission, 2021). This is in line with the documents of the DIRECTED project, as they indicate that a complex structure and interplay of responsibility of different actors were present in the Erft-region during the 2021 flooding.

Uncertainty arises in part from the complexity. As stated above, although heavy precipitation was forecasted two days in advance, the forecast was precisely only a few hours before the event. These facts underline the uncertainty of heavy rainfall events as they are not precisely predicable in the long run. The great uncertainty of such extreme weather events is connected to the uncertainty and complexity of climate change. An attribution study indicates that due to global warming the probability of such events in Western Europe increased by a factor of 1.2 to 9 which creates great uncertainty with regard to the measures that need to be taken (Tradowsky et al., 2023). In addition, there were uncertainties among institutions and decision-makers during the 2021 floods. From documents of the DIRECTED project, it can be derived that cooperation between stakeholders has not been sufficient during the disaster and each actor was uncertain about the areas of tasks, working methods and responsibilities of other actors. This strategic uncertainty exacerbated the difficulties of the disaster management (Dewulf & Biesbroek, 2018)

Ambiguity arises from the different interpretation of data and leads to different conclusions for implications for action. Although precipitation forecasts were available a few hours before the disaster (Kron et al., 2022; Mohr et al., 2023), there were different assessments of the data by different bodies, resulting in insufficient recommendations for action by decision-makers. Although the warning level 4 and the precipitation forecast by the DWD was published a few hours before the event, decision-makers have not been aware which dramatic consequences this rainfall will have, leading to insufficient early warning (Kron et al., 2022; Thieken, Bubeck, et al., 2023). This fact is also reflected in the statements made by stakeholders of the DIRECTED project. Although data on water levels was available, the responsible persons in the disaster area did not know what practical implications this data had and what specific measures needed to be taken.

During the flood disaster, different system components interacted, which contributed to an aggravation of the situation as a *transboundary effect*. The flood caused damage to power substations, resulting in widespread, prolonged power outages that made crisis management more difficult (Kron et al., 2022). In addition, the critical infrastructure (e.g. hospitals and fire brigades) was partially unusable from a certain point onwards as they have been destroyed themselves or unreachable due to destroyed traffic routes (ÄrzteZeitung, 2021a). Destroyed transportation infrastructure impeded the humanitarian situation in the crisis area as the supply of relief aid and urgently needed medicines has been interrupted (Thomas, 2021). Furthermore, there were problems with the water and sewage supply. In combination with corpses and animal carcasses that had not been cleared away, this led to an increased risk of epidemics (Gries, 2021). One of the decisive transboundary effects of the flood was that communication channels were massively impaired due to the interrupted power supply. After the breakdown of communication due to lack of electricity, the emergency services were left to their own devices and no longer received any information about the further course of the disaster (Kron et al., 2022). In addition, the emergency services were not prepared to act on their own initiative in the event of a disaster, which resulted in an inability to make decisions on site (Nick et al., 2023). This is in line with the DIRECTED documents which indicate that after the collapse of the technical communication channels, disaster management was hardly or no longer possible, with further catastrophic consequences.

The fifth feature, *stochastic and non-linear relationships with tipping points*, was displayed in the 2021 flooding when bridges stated to be blocked by debris. Thereby, these bridges became catchment lakes, leading to rising water levels without any additional rainfall (Kron et al., 2022). The collapse of electricity leading to a collapse of technical communication, which in turn impeded effective disaster management, can be defined as tipping points within the disaster, showing the non-linearity between multiple causes and their effects. The heavy rainfall resulting in a flood disaster is also linked to the consequences of climate change. The origin of climate change lies in the continuous rise in greenhouse gas emissions, which have led and will continue to lead to rising average global temperatures. Although scientists clearly state that rising global temperatures are leading to more frequent and more intense extreme weather events, the resulting accumulation of extreme weather events is difficult to calculate locally and almost impossible to precisely forecast (Tradowsky et al., 2023). The interconnectedness of climate change and extreme weather events possibly leading to flood disasters thereby creates a non-linear stochastic cause-effect relationship.

5.2 Analysis of the existing risk governance approach in the Erft valley during the 2021 flooding

In this qualitative content analysis, the data from the DIRECTED project is analysed based on the IRGC guidelines for systemic risk governance to answer the second research question and its two subquestions.

2. Has the existing approach to risk governance in the case of the Erft valley led to *worse crisis management* of the flood disaster compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.1. Has the existing approach to risk governance led to *poorer communication* between involved stakeholders compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.2. Has the existing approach to risk governance led to *poorer information sharing* from the stakeholders' perspective compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?

The participating actors of the DIRECTED project were interviewed on various aspects of local disaster risk management during the 2021 floods and stakeholder workshops were conducted. The chart with the seven steps and the extracted single criteria for each step in the chapter 4.3 Operationalisation are used for the qualitative analysis. Detailed operationalisation charts with statements and their categorisation from stakeholder 1 (SH1) can be found in Appendix A, from stakeholder 2 (SH2) in Appendix B and from the stakeholder workshops (SHW) in Appendix C. When examining the extent to which the statements extracted from the documents correspond to the required steps of the IRGC, it must be taken into account that the approach to systemic risk governance described in the IRGC was not the subject of the interviews and workshops and is therefore only partially reflected in the statements. Nevertheless, the IRGC guidelines can serve as a basis for analysing the governance structures in place at the time to examine whether this has led to worse crisis management. The investigation of the system under consideration was indirectly addressed in the surveys and workshops. In addition, the description of the problems that arose and the proposed solutions in retrospect provide a picture of the structures in place at the time of the crisis. Steps 6-7 were not the focus of the survey and the previous stakeholder meetings. From this, as well as from other gaps in the tabular comparison, suggestions for further processing by the actors involved can be obtained.

The *first step* is to get an overview of the system and its environment. The first single criterion concerns *scanning and analysing the organisation's internal environment and boundaries*. SH1 states that „the flood event hit the region completely unprepared". From this one can conclude that the internal structure of the organisation was not prepared for a disaster of this magnitude. The examination of the existing governance structure is mentioned as a task in the SHW but is not elaborated on further. However, there is an indication that already established relationships within the flood protection corporations, particularly within the municipalities of SH1 and SH2, should be used. The second single criterion is about *scanning and analysing the organisation's external environment and boundaries*. The mentioned desire for close cooperation in the event of a flood suggests that cooperation between the stakeholders involved has not been sufficient in the past (SH2). In addition, it was mentioned that stakeholders such as the district government of Cologne, the state of North Rhine-Westphalia and the German Weather Service (DWD) were missing from the project (SH2). This leads to the assumption that this integration was not present during the flood disaster either. Interestingly, the federal government and the state government of Rhineland-Palatinate are not mentioned. The magnitude of such a flood was unimaginable for those involved and they were not aware of the consequences (SH1). Stakeholders have different areas of requirement. In this context, SH1 found that a mutual understanding of tasks, working methods and areas of responsibility would be particularly important. It is also added that there should be representatives from the municipalities (SH1, SHW). From this it can be concluded that the required degree of transparency and cooperation with the external environment was not given. The operational level of flood control is ensured by the fire brigades (SHW). In addition, the meetings included a presentation of the structures and tasks of disaster control at the federal state and district level (SHW). It can be interpreted from this that the *boundaries of the system* have been recognised as barriers and that the exchange is to be improved by creating communication intersections. The districts are responsible for disaster control (SHW). The desire for active exchange between districts and SH3 can be interpreted as meaning that the situation was previously suboptimal (SHW). There is a clear division of tasks between SH3 and the German Weather Service (DWD). SH3 is responsible for monitoring water levels and the DWD warns of precipitation events (SHW). Apparently, there was not enough exchange between the various municipalities about alarm and emergency plans. An exchange on this is planned. The third single criterion is about investigation the *position of the organisation and its interconnectedness with other systems*. In this context, SH2 addresses the creation of a supra-regional connection between water authorities and civil protection of municipalities and districts of the catchment area. This suggests that there was no such link between the systems in the event of the flooding. For the fourth single criterion *institutional capacities for analysing the environment* was no direct information found in the surveys. It would be interesting to investigate whether the capacity is sufficient for this task. With regard to resources, it is noted that disaster control is not equipped in terms of material and personnel for damage minimisation in the event of a disaster of this magnitude (SH1). In addition, it was mentioned that there are not enough human resources to ensure professional interpretation of the data by experts for each district control centre (Kreiskatastrophenschutzstelle) in the event of a crisis (SHW). As part of a solution, SH3 is planning to set up a "situation centre" for disasters so that personnel capacities can be reduced and officers of the municipalities can be contacted from there. The fifth single criterion is about *communication and collaboration with others (diversity of information)*. According to the stakeholders, the necessary information is available, but expertise is needed to interpret the data (SHW). SH3 offers to assist with information, technical support and training on interpreting the data (SHW). Until now, the governance structure was not optimised to ensure a flow of information for all parties involved. Therefore, stakeholders propose to create a more appropriate governance structure that contributes to a better and more open flow of communication before and during a crisis (SH1, SH2). From these statements it can be drawn that due to the lack of interpretation of the data, the population was also not sufficiently informed about the situation. It is also stated that the water boards should be actively involved in hazard prevention and disaster control in the future (SH2). Furthermore, the exchange between crisis management and SH3 is addressed as a problem during the flood disaster (SH2). From this it can be concluded that such an exchange was not planned before the disaster. Based on the statement that a greater awareness of self-preparation among the population in the event of a flood would be welcome, it can be assumed that the population was not sufficiently sensitised to the topic before the flood (SH1). Moreover, the involvement of the politically responsible level in the drafting of preventive action plans is called for, as these generate costs even in the absence of a disaster. This leads to the assumption that the politically responsible level was not sufficiently involved before the flood disaster (SH1). The sixth single criterion is a *scientific approach to data collection, analysis and priorisation*. SH2 would like to see improvements in forecasting and evaluation systems as well as advice from experts in the event of severe weather hazards (SH2). The technical data was available, but there were difficulties in interpreting the data (SHW). The stakeholders would have needed professional advice on the interpretation of the data during the flood (SH2, SHW). With regard to HOWIS, the flood information and warning system Erft, stakeholders would like to see a data preparation and training provided (SHW), so that it can be used more effectively. Apparently, this was not the case before. SH3 is planning to create flood hazard maps to make the data easier to interpret (SHW). In addition, SH3 can support the interpretation of data and its uncertainties and provide discharge forecasts (SHW). Neither was apparently the case during the flood. The last single criterion of the first step is the *environment scanning for weak / early warning signals*. HOWIS provides valuable information and is continuously monitored by the lower water authority, according to SH2. However, SH2 notes that before and during the occurrence of a hazard, this data must be actively forwarded. This suggests that no such forwarding of data took place during the 2021 flood disaster.

The *second step* of the IRGC guidelines is about *developing scenarios, considering ongoing and potential future transitions*. The first single criterion is to *develop scenarios of future developments (alternative futures), including low probability scenarios*. SH2 expressed the desire for scenario definitions that trigger automated processes in the event of a disaster. As part of such a process, on-site crisis management counselling should take place (SH2). There is also a request to define in advance who is responsible for initiating which measures in the event of a disaster (SH1). In the stakeholder workshops, the topic of extreme scenarios of dams being overflowed or breached is addressed in order to develop evacuation plans for the affected areas (SHW). It is noted that the simulation of flood events is already working well (SHW). The second single criterion is *potential future transitions*. In this context, it is mentioned that scenarios and simulations also determine possible damage potential as a potential future transition (SHW).

The *third step* involves *determining goals and the level of tolerability for risk and uncertainty* that the system should have. The first single criterion *short-, medium- and long-term objectives* are mentioned indirectly in the surveys and stakeholder meetings. SH2 says that all stakeholders should be involved to improve forecasting and assessment systems for severe weather hazards to provide advice to hazard prevention authorities. In addition, SH1 states that the aim of the project is to find useful solutions in the field of disaster protection and water management that lead to greater resilience to heavy rainfall and flood events in the region. In the stakeholder workshops, it was also stated that a "uniform shared awareness" should be established. The second single criterion is *business or economic goals*. In this context, the need for optimization measures for civil protection is mentioned, as they are not capable to mitigate extreme floods alone (SH1). The third single criterion is about *normative goals* and there are several of them mentioned. The governance structures should be improved in a way that during hazard disaster situations there is flow of information for all stakeholders (SH2, SHW). In addition, the facilitation of communication and cooperation between all stakeholders should build resilience and contribute to the minimization of the impact due to heavy rain and floods (SH2, SH1). Furthermore, weather forecasts are to be improved through increased information exchange between SH3 and other stakeholders (SHW). The aim of the DIRECTED project is to improve disaster risk management together with stakeholders and to find concrete improvements for the region (SHW). The fourth single criterion touches upon the *tolerability for risk and uncertainty*. For this criterion, there are only indirect statements that always refer to risk avoidance in general. The importance of involving the politically responsible level is also mentioned, as prevention measures are costly even when there is no severe weather at the time (SH1). This is an indicator that the public perception of the risk was not strong enough in the past and this action might increase willingness to spend more money on prevention measures.

The fourth step is about how to *co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition.* A key element of the management strategies is to *co-develop* *solutions with other actors*, which displays the first single criterion. In general, there is a desire to develop more appropriate governance structures that ensure an open and trusting flow of information between all stakeholders before and during a disaster and thus contribute to prevention and resilience (SH2). The establishment of a working group for the catchment area is suggested as a concrete improvement for the flow of information (SH2). Being familiar with each other's ways of operating and maintaining a close dialogue in advance can facilitate cooperation in the event of a crisis (SH2). From these statements it can be concluded that in the past stakeholders have not been working sufficiently close enough together. In the future, consultancy by SH3 is to play a special role (SH2). The aim is to automate the process of providing expert advice to municipalities' crisis management teams in accordance with the relevant workflows (SH2). Disaster plans for local disaster control measures are to be drawn up in advance (SH2). In this context, SH1 also emphasises that it would be an improvement if it were clarified beforehand which measures would be taken by whom in the event of a disaster. Moreover, the lower disaster control authorities need meaningful forecasts from which concrete measures with time schedules can be derived for the local units during a disaster (SH1). As these preventive action plans are associated with costs, the political level should also be involved (SH1). The workshops led to the idea of initiating online meetings with the districts and the hydrological experts from SH3 in order to look at weather forecasts for heavy rainfall in particular (SHW). Another consideration concerns the involvement of municipal representatives (SHW). Additionally, the municipalities could be informed about DIRECTED by SH3 (SHW). SH3 can also provide technical support outside the official warning and information chain and offer accompanying HOWIS training courses (SHW). In the further course, a focus will be placed on a continuous exchange, the expansion of the network and the involvement of project partners with different expertise (SHW). These measures are intended to improve risk governance, especially with regard to flood protection (SHW). The second single criterion is to *build resilience and encourage self-organisation*. According to SH2, the ability of the individual stakeholders to act may be improved through transparent communication, particularly in terms of sharing know-how and technical expertise. SH1 notes that above a certain predicted risk level, measures need to be taken which can be provided by the relevant stakeholders themselves if possible. Under the assessment of the IRGC we can identify that by adopting this approach, the individual stakeholders' ability to act can be improved even in the event of communication difficulties. Stakeholders also identified the need to raise public awareness of the issue of flooding, to better inform people about the specific impact of certain water levels where they live and to make them aware of the danger of flowing debris and water currents (SHW). Besides the population, districts should also be able to act more independently (SHW). To achieve this, the districts are to learn how to better use and interpret HOWIS data through workshops with SH3 (SHW). The third single criterion of co-developing management strategies is to *prepare for disruptions, accidents and crises*. According to the stakeholders, improving communication plays a central role in crisis management. For this purpose, SH2 called for an optimisation of the structures, in particular the exchange between crisis management and SH3 (SH2). According to the stakeholder workshops, a solution must be found to the problem of the technical breakdown of communication channels (BOS digital radio for security authorities and organisations, landline telephony, mobile telephony). Finally, the fourth single criterion is to *address scenarios from step 2 with a list of management strategies*. Within the framework of the project, SH2 would like to see automated processes developed on the basis of various scenarios that include the deployment of specialists to advise on local crisis management. During the stakeholder workshops, the scenario of a dam burst was developed in order to identify evacuation areas below the dam by using a simulation (SHW). This can serve as a basis for evacuation plans (SHW). From this information it can be assumed that such management strategies with evacuation plans have not been present before the 2021 flooding leading to difficulties how to act and e.g. evacuate during the crisis.

Step 5 deals with *unanticipated barriers and sudden critical shifts*. In the event of a crisis, it may not be possible to fall back on the previous steps and the process can be started entering with this step. The first single criterion is to deduct *deliberative exercises* to *identify and overcome barriers*. According to SH2, there were problems in communication with the flood protection facilities and between the crisis management and SH3 during the 2021 flooding. On top of this, there were difficulties with the technical communication channels at all levels (SH2). In order to recognise and overcome barriers in future, a network is to be created and meetings planned with SH3 (SHW). In the project, stakeholders identified communication and data (HOWIS), among other things, as barriers during the 2021 floods (SHW). As second single criterion it is important that *all involved stakeholders are prepared and legitimised to overcome barriers.* In this respect, there is a reference in the documents to the fact that in future, measures can be implemented by the relevant stakeholders themselves (SH1). Moreover, trainings and the provision of data in the online portal HOWIS have already begun in order to overcome the barriers of lack of communication and lack of expertise knowledge (SHW). The third single criterion is *transparency, agility and creativity to overcome a blockad*e. One aspect of transparency that is addressed could be that information on the flood protection basins should also be sent to the districts in future and not just to the district government in Cologne. This forwarding leads to greater transparency and might increase agility in the case of a future crisis.

Step 6 is to *decide, test, and implement strategies*. The five extracted single criteria are: Compare the strategy options developed in steps 4 and 5; Test and experiment strategies; Decide which strategies to implement; Clear and transparent decision-making criteria; Involve all stakeholders in decision-making. Only the second single criterion test and experiment strategies are indirectly addressed through a simulation game in the stakeholder workshops. Due to the fact that the DIRECTED project is still in the process and not finished by now it can be assumed that further criteria from step 6 might be fulfilled in the future.

Step 7 *monitor, learn from implementation, review and adapt* is intended to create the conditions for a learning organisation. The extracted single criteria comprise regular monitoring of the strategies, learn from implementation, review and adapt, flexibility through adjustment loops and iterative processes. So far there are no relating statements in the documents on this topic. This is probably also due to the fact that actors have not yet reached this point in the process and questions of continuous improvement might become relevant at a later point in time.

6. Discussion of results

In terms of fatalities, the flood was the largest flood disaster in Germany since 1962 and is linked to the systemic risk of anthropogenic climate change. With the support of RIFS, the Erftverband and the affected districts have adopted a systemic approach within the framework of DIRECTED in order to be better prepared for future disasters. The knowledge gained so far in this project should help to answer the following research questions.

1. Was the 2021 flooding in the Erft valley a systemic risk?
2. Has the existing approach to risk governance in the case of the Erft valley led to *worse crisis managemen*t of the flood disaster compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.1. Has the existing approach to risk governance led to *poorer communication* between involved stakeholders compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?
   2.2. Has the existing approach to risk governance led to *poorer information sharing* from the stakeholders' perspective compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks?

The first research question concerns the classification of the disaster as a systemic risk. There are strong indications that the 2021 flood is a systemic risk, as the damage, in particular the number of deaths, was caused by a combination of various factors linked to complexity, uncertainty, ambiguity, transboundary effects, and non-linear cause-effect-relationships with tipping points. Based on the available data, it was possible to establish a match for each individual factor on the basis of the relevant literature on the respective defined factors for systemic risks. First, *complexity* stems from the fact that the cause of the flooding, the weather, is itself very complex. Secondly, the consequences of a heavy rainfall event are highly dependent on the region, i.e. the context. It is therefore not possible to formulate a generalised consequence, as the same amount of precipitation in another region would not have led to such a major flood disaster. Thirdly, human organisational structures are characterised by complexity and fragmentation and are therefore susceptible to disruption. Due to the complexity of the causes of the extreme weather event, there were great uncertainties in making an early, precise and reliable weather forecast in terms of time and location. This uncertainty is linked to the systemic risk of global warming with the increasingly frequent occurrence of more extreme weather events. Uncertainty also arises in crisis management in the event of a disaster due to the lack of clarity in the interaction between stakeholders and responsibilities in the fragmented administrative system. In addition to uncertainties, *ambiguity* also played a key role in the management of the flood. On site, different interpretations of the weather forecast data led to different recommendations for action and to poor crisis management. The flood also had *transboundary effects*, as it caused damage to critical infrastructure (e.g. hospitals), transport routes, electricity and water supplies and technical communications, leading to restrictions and in some cases complete breakdowns in communication, medical care, transport of relief supplies, evacuation of people and coordination of protective measures. *Stochastic and non-linear relationships with tipping points* were evident in the form of blocked bridges that became dams, the collapse of the power supply and technical means of communication. In addition, climate change leads statistically to more frequent and more intense heavy rainfall events, which are difficult to calculate and predict in terms of location and time, which emphasises the non-linear relationship. Due to the interplay of all these factors, the flood can be categorised as a systemic risk and the first research question can be answered in the affirmative. This results in the need for a governance approach that is suitable for systemic risks.

The second research question concerns the existing approach to risk governance in the case of the Erft valley and if it led to worse crisis management of the flood disaster compared to the standards set by the IRGC Guidelines for the Governance of Systemic Risks. This question and its two subquestions can be answered by qualitatively analysing the DIRECTED documents with regard to the IRGC Guidelines. The documents indicate several aspects which led to difficulties in crisis management and are outlined below. In addition, solutions to some of the difficulties are proposed. From the difficulties mentioned and the existing potential for improvement, it can be concluded that the previous governance approach was insufficient. The documents show that the region was inadequately prepared for the disaster and that there was a lack of mutual understanding of the respective tasks and areas of responsibility. It is explicitly mentioned that there were difficulties in communication between several stakeholders during the disaster. It can be concluded from this that the individual stakeholders did not cooperate sufficiently with each other and that there was a lack of communication and transparency. In order to improve governance structures, stakeholders want to establish an open and trusting flow of information between all stakeholders that enables the sharing of know-how and expertise. In addition, there are plans to establish supra-regional cooperation for the co-evolution of structures and action plans to help the individual stakeholders and contribute to the overall resilience of the system. This leads to the conclusion that such an interface did not exist before and that each stakeholder had its own structures, indicating a fragmented governance approach. Another important aspect is the definition of threshold values that lead to the initiation of automated action sequences. Now it is planned that responsibilities will be delegated in advance, indicating that in the wake of the crisis it was not completely clear who was responsible for what action. There will be training courses on how to interpret data correctly, as well as on how to practise processes to overcome a lack of communication and expertise. At the same time, local civil protection units should be encouraged and authorised to act independently in the event of a crisis. Simulations can help to develop emergency plans. In the aftermath of the disaster, a dam burst simulation was used to develop evacuation plans. The possible effects of flood scenarios should be constantly published and the awareness and self-protection of the population should be strengthened. Both prevention and the provision of resources for crisis management cost money. The population, decision-makers and political responsible level need to be informed so that they can weigh up the associated costs against the potential damage. Although HOWIS provided data during the crisis, it is suggested that this data should be actively forwarded to lower water authorities, implying a lack of sharing and attention to the data during the disaster. SH3 is not operationally responsible in the event of a crisis but might act as a central interface for information and expertise in the future. With regard to the second research question, the analysis provides many indications that prior orientation to the IRGC guidelines would have helped to minimise the damage and, in particular, the number of fatalities. The analysis clearly points out a fragmented governance approach which led to a worse crisis management during the flooding. On this basis, the second research question can be answered in the affirmative.

The second research question has two subquestions which specifically examine the existing approach to risk governance regarding *communication* and *information sharing*. The importance of effective communication was emphasised in all available documents. Both the establishment of communication structures in advance and the improvement of communication in the event of a crisis were addressed. The people on site and the districts as the coordinating body were cut off from important information during the 2021 flood. Scenarios and procedures have not been practised in advance and it was unclear who was responsible for which tasks at the stages of the disaster. Expertise would have been helpful in interpreting data, but at a certain point communication was no longer possible for technical reasons. The importance of communication is a key factor in overcoming crises and was the most frequently mentioned aspect in the documents. At the critical stages of the flooding, there was a lack of communication among other things because suitable, appropriate routines had not been established. Research question 2.1 can therefore be answered in the affirmative. But it should be noted that communication alone cannot immediately solve all problems in the event of a crisis. Preparations with regard to the processing of data to assess the degree of risk, the provision of emergency plans and threshold values for their initiation would strengthen and accelerate the ability to act on the scene. The analysis clearly shows that during the flooding there was a lack of data sharing between stakeholders. Moreover, expertise on site was missing to interpret the data correctly, suggesting that there was also a lack of sharing of expertise. Consequently, it is not only communication that is important, but also that information sharing is crucial for action on site. Missing information on site was a second key factor which led to poorer crisis management. This means that research question 2.2 can also be answered in the affirmative.

The results of the DIRECTED project to date reveal a situation of organisational fragmentation between municipalities, districts and the Erftverband in the event of a crisis, with a lack of communication both internally and externally and a lack of exchange of information, knowledge and expertise. Furthermore, employees and the general public were not made aware of flooding scenarios in advance and there was a lack of early warning in the wake of the flooding. It can be assumed that if sufficient information had been provided and the data had been interpreted correctly with an appropriate assessment of the situation, evacuation would have been carried out earlier and many deaths could have been avoided. The DIRECTED programme is working on these aspects and it can be assumed that in the event of a future crisis - on the same scale as the 2021 flood - at least the damage in terms of fatalities can be minimised. The efforts made so far by the stakeholders as part of the DIRECTED project cover most of the aspects addressed in steps 1-5 of the IRGC guidelines. At the time of writing, there is little material available on the last two steps of the IRGC guidelines, which concern implementation and any subsequent adjustments. A decisive advantage of the IRGC guidelines is that the work is cyclical and that step 7 is followed by step 1. This would ensure that the topic remains permanently present and that the system is adapted to current conditions. Given the unpredictable nature of systemic risks and the increasing frequency of flooding identified in the attribution study, such a continuous improvement process will be helpful in overcoming the growing challenges.

Despite all these insights, there are some limitations to the analysis. The guidelines developed by the IRGC for the governance of systemic risks were selected as a benchmark for good governance of systemic risks. As the IRGC guidelines have been developed for all types of systemic risks, not all details fit the event of a flood disaster. It is beyond the scope of this paper to go into all the details of the IRGC guidelines. Accordingly, it is not possible to harmonise these documents with all aspects of the IRGC. A selection was made, taking into account aspects that overlapped between the IRGC and these documents. A further limitation is the timing of the study. The project is still ongoing and contributions to steps 6 and 7 in particular could still follow.

7. Recommendations

Due to global warming the probability of an occurrence of a flooding with the same magnitude as the one in 2021 is increased by a factor of 1.2 to 9 (Tradowsky et al., 2023). As global average temperatures continue to rise, the frequency and severity of extreme weather events are likely to increase even more. This development should be communicated well and all stakeholders and decision-makers in the region should be aware of this trend. The outlook of increased global warming and its severe implication make a transition to governance structures that are suitable for systemic risks indispensable and it is crucial to build more resilience within societies.

The analysis has shown that the changes that have now been developed, particularly in the communication structures, will enable people to be warned earlier in the future. This alone provides better protection for the population. Maintaining awareness and continuously working on a systemic risk approach is crucial to keeping management strategies flexible and accounting for changes in the internal and external environment. The best option would be to continue the DIRECTED project on an ongoing basis. If this is not possible, stakeholders should continue the process of close collaboration, information sharing and following the steps of the IRGC Guidelines to be able to act cohesively and self-encouraged in the event of a disaster.

From the stakeholders' perspective, the fragmented governance approach and the unclear distribution of responsibilities between the water boards, districts and municipalities led to poorer crisis management mainly due to the restricted flow of communication and information. Apart from potential disadvantages, decentralised structures have the advantage in theory that they remain operational in the event of a crisis as long as it is ensured that all actors are legitimised and capable of acting. One possible solution is therefore not to centralise the system, but to establish inclusive governance structures in order to facilitate fluid communication and make existing knowledge available to all stakeholders in a transparent manner. As the administrative structures are similar throughout Germany and climate change will lead to challenges and potential damage in all regions in the future, the results of this work could also provide recommendations for action for other regions and the reorganisation of their governance approaches.

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9. Appendices

9.1 Appendix A: Chart of qualitative analysis: Survey with stakeholder 1 (SH1)

Survey with stakeholder 1 (SH1)

IRGC Steps	Short description of the step	Single criteria	Related content of survey
Step 1	Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment.	Scanning and analysing the organisation's internal environment and boundaries	*"The flood event hit the region completely unprepared."*
		Scanning and analysing the organisation's external environment and boundaries	*"Awareness of heavy rainfall and flooding, or the consequences of their coincidence, had not been raised. The event had a hitherto unimaginable dimension."* *"Different responsibilities of different stakeholders, Kommune, Wasserverband"* *"Development of a mutual understanding of the tasks, responsibilities, working methods as well as the performance of the stakeholders is important"* *"it could be helpful if municipal representatives of cities/communities are consulted."*
		Position of the organisation and interconnectedness with other systems	
		Institutional capacities for analysing the environment	*Major damage minimisation in the event of such a huge disaster: „ cannot be handled by civil protection alone", "Civil protection is not equipped to do so, neither in terms of personnel nor material."*
		Communication and collaboration with others (diversity of information)	*"a flow of information between the stakeholders in the run-up to potential disasters, a stronger awareness of the population with regard to self preparedness would be welcome."*

			"Since the preventive action plans also have an external impact and costs in the absence of a disaster, these action plans should also be coordinated with the politically responsible level and harmonized between the districts."
		Scientific approach to data collection, analysis and priorisation	
		Environment scanning for weak / early warning signals	*Suggestions for changes in existing governance structures: "The installation of a "pre-warning level" for which action plans, action carriers, time sequences, etc. are determined, could contribute to damage minimization."* *„Even though forecasts of floods and heavy rainfall are generally subject to high uncertainties, measures could be taken in advance of an impending catastrophe once* ***certain forecast hazards have been reached****. "*
Step 2	Develop scenarios, considering ongoing and potential future transitions.	Develop scenarios of future developments (alternative futures), including low probability scenarios	*"It could be determined* ***which measures*** *could be taken and* ***by whom****, especially in advance of a flood or heavy rain event."*
		Potential future transitions	
Step 3	Determine goals and the level of tolerability for risk and uncertainty.	Short-, Medium- and long term goals	*"project produces usable results that can be utilized in the context of* ***disaster protection and water management****. The results should be concrete enough that after their implementation they lead to a* ***stronger resilience*** *of the project region, especially with regard to heavy rain and floods."*
		Business or economic goals	*"it is not feasible for civil protection alone to limit the damage to the minimum possible*

			extent in the event of extreme floods/extreme heavy rain events occurring at short notice. Here, DIRECTED would have the opportunity to ***elicit optimization measures****.”*
		Normative goals	*“Improving resilience in regard to heavy rain and flood”*
		Tolerability for risk and uncertainty	*„damage is minimized“* *„Since the preventive action plans also have an external impact and costs in the absence of a disaster, these action plans should also be coordinated with the politically responsible level and harmonized between the districts.“*
Step 4	Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition.	Co-develop solutions with other actors	*“Here, DIRECTED would have the opportunity to elicit optimization measures. It could be determined* ***which measures*** *could be taken and* ***by whom****, especially in advance of a flood or heavy rain event.”* *“From the point of view of a lower disaster control authority,* ***meaningful forecasts*** *are required for crisis management in the event of high water / heavy rainfall, from which* ***manageable measures for the local units can be derived****. These forecasts and packages of measures should take into account the* ***required timelines for the initiation of emergency response measures****.”* *“Since the preventive action plans also have an external impact and costs in the absence of a disaster,* ***these action plans should also be coordinated with the politically responsible level and harmonized between the districts****.”*
		Build resilience – encourage self-organisation	*„measures could be taken in advance of an impending catastrophe once certain forecast hazards have been reached.*

			These should be measures that could be taken by the relevant actors, e.g. the municipality, water board, etc. Advice could also be given on how to activate the own precautionary measures of commercial enterprises and private households. “
		Prepare for disruptions, accidents, crises	
		Address scenarios from step 2 (with a list of management strategies)	
Step 5	Address unanticipated barriers and sudden critical shifts that may come up during the process.	deliberative exercises to identify and overcome barriers	
		All involved stakeholders prepared and legitimised to overcome barriers	*“Even though forecasts of floods and heavy rainfall are generally subject to high uncertainties, measures could be taken in advance of an impending catastrophe once certain forecast hazards have been reached. These should be* ***measures that could be taken by the relevant actors*** *(deutsch: in Eigenleistung), e.g. the municipality, water board, etc.. Advice could also be given on how to activate the own precautionary measures of commercial enterprises and private households.”*
		Transparency, agility, openness to innovation (to overcome barriers)	
Step 6	Decide, test and implement strategies.	Compare the strategy options developed in steps 4 and 5	
		Test and experiment strategies	
		decide which strategies to implement	

		Clear and transparent decision-making criteria	
		Involve all stakeholders in decision-making	
Step 7	Monitor, learn from implementation, review and adapt.	Regular monitoring of the strategies	
		Learn from implementation	
		Review and adapt	
		Flexibility through adjustment loops and iterative processes	

9.2 Appendix B: Chart of qualitative analysis: Survey with stakeholder 2 (SH2)

Survey with stakeholder 2 (SH2)

IRGC Steps	Short description of the step	Single criteria	Related content in survey
Step 1	Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment.	Scanning and analysing the organisation's internal environment and boundaries	
		Scanning and analysing the organisation's external environment and boundaries	*"Suggestions for changes in existing governance structures: Open and trusting communication between all stakeholders involved in the event of a flood; getting to know each other's working methods in the event of a crisis as well as clearly naming and discussing wishes, goals and obstacles for this close cooperation"* *"Misssing stakeholders:district government Cologne (among others as supervisory authority for technical flood protection measures), Level of the State of North Rhine-Westphalia / district governments; State Agency for Nature, Environment and Consumer Protection (LANUV);*

		German Meteorological Service (DWD)"
	Position of the organisation and interconnectedness with other systems	*"Idea where DIRECTED could start: Supra-regional connection of water authorities and civil protection of the respective municipalities and districts of the catchment area for an exchange and joint development of protection and action strategies"*
	Institutional capacities for analysing the environment	
	Communication and collaboration with others (diversity of information)	*"The stakeholders involved can improve their ability to act in the event of a crisis through open communication about risk and vulnerability."* *"(So far) lack of active involvement of the water boards in hazard prevention / disaster control (especially in case of floods)"* *Difficulties in the 2021 flood: "In the early communication on the operation of flood protection facilities; Exchange between crisis management and SH3. Further technical communication difficulties at all levels (BOS digital radio, fixed network telephony, mobile telephony)."*
	Scientific approach to data collection, analysis and priorisation	*HOWIS related:"Use in regular operation as an information portal for hazard prevention / the unified control center (fire protection, disaster control and rescue service). In extreme weather situations with multiple influencing factors, the professional evaluation by the emergency forces for the situation assessment of the hazard prevention is not possible. This* ***requires the advice of knowledgeable persons (experts).***"

		Environment scanning for weak / early warning signals	*"HOWIS is constantly (co-)monitored in the lower water authority; it provides valuable information; "**active data transmission" would be required** before and during a hazard prevention/disaster case;´."*
Step 2	Develop scenarios, considering ongoing and potential future transitions.	Develop scenarios of future developments (alternative futures), including low probability scenarios	*"Automated workflow processes according to scenario definition for dispatching the specialist consultancy in the municipal crisis management."*
		Potential future transitions	
Step 3	Determine goals and the level of tolerability for risk and uncertainty.	Short-, Medium- and long term goals	*„Involving ALL stakeholders to improve forecasting and assessment systems for severe weather hazards to advise hazard prevention authorities."*
		Business or economic goals	
		Normative goals	*"Improvement of the structures for hazard prevention/disaster situations, especially the **communication and cooperation** of all important players."* *"Establishing appropriate governance structures that facilitate the flow of information for all stakeholders before and during a disaster and contribute to prevention and resilience building."*
		Tolerability for risk and uncertainty	
Step 4	Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition.	Co-develop solutions with other actors	*"Establishing appropriate governance structures that facilitate the flow of information for all stakeholders before and during a disaster and contribute to prevention and resilience building."* *"Optimization of processes in risk and crisis communication with the participation of the SH3 expert advisory service."*

		"Automated workflow processes according to scenario definition for dispatching the specialist consultancy in the municipal crisis management." Suggestions for changes in existing governance structures: *"Preparedness planning and operational planning of local emergency response authorities and disaster management institutions. Open and trusting communication between all stakeholders involved in the event of a flood; getting to know each other's working methods in the event of a crisis as well as clearly naming and discussing wishes, goals and obstacles for this close cooperation"* *"In terms of risk governance, the formation of a "working group" for the catchment area is certainly a good starting point; in this way, the concerns of upstream and downstream riparians can be exchanged"*
	Build resilience – encourage self-organisation	*"Within the framework of risk governance, structures based on trust could be created for the crisis situation. The stakeholders involved can **improve their ability to act in the event of a crisis through open communication** about risk and vulnerability. This does not even require assuming decision-making responsibility. **Knowledge and technical expertise must be shared**"*
	Prepare for disruptions, accidents, crises	*"Improvement of the structures for hazard prevention/disaster situations, especially the communication and cooperation of all important players."* *"Optimization of processes in risk and crisis communication with the participation of the SH3 expert advisory service."*

			"Exchange between crisis management and the SH3. Further technicalcommunication difficulties at all levels (BOS digital radio, fixed network telephony, mobile telephony)."
		Address scenarios from step 2 (with a list of management strategies)	*"Automated workflow processes according to scenario definition for dispatching the specialist consultancy in the municipal crisis management."*
Step 5	Address unanticipated barriers and sudden critical shifts that may come up during the process.	deliberative exercises to identify and overcome barriers	Difficulties in the 2021 flood: *"In the early communication on the operation of flood protection facilities (example: Eicherscheid, Horchheim);* *"Lack of data (operating plans technical flood protection measures)"* *"Exchange between crisis management and the SH3. Further technical communication difficulties at all levels (BOS digital radio, fixed network telephony, mobile telephony)."*
		All involved stakeholders prepared and legitimised to overcome barriers	
		Transparency, agility, openness to innovation (to overcome barriers)	
Step 6	Decide, test and implement strategies.	Compare the strategy options developed in steps 4 and 5	
		Test and experiment strategies	
		decide which strategies to implement	
		Clear and transparent decision-making criteria	
		Involve all stakeholders in decision-making	

Step 7	Monitor, learn from implementation, review and adapt.	Regular monitoring of the strategies	
		Learn from implementation	
		Review and adapt	
		Flexibility through adjustment loops and iterative processes	

9.3 Appendix C: Chart of qualitative analysis: Stakeholder workshops (SHW)

Stakeholder workshops (SHW)

IRGC Steps	Short description of the step	Single criteria	Related content of documents
Step 1	Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment.	Scanning and analysing the organisation's internal environment and boundaries	*"The SH3 builds and manages a Real World Lab (RWL), comprising the districts of SH1 and SH2. In order to develop adapted solutions to improve disaster risk management (DRM) with relevant stakeholders in this RWL, existing governance structures and climate change strategies are analysed and problems are identified. The project aims to transfer the results to the entire catchment of the Erft."* *"relationships already established within the flood protection corporation should be used; especially with the municipalities in the districts of Euskirchen and Rhine-Erft"*
		Scanning and analysing the organisation's external environment and boundaries	*"Operational options and limits of a municipal fire department in the event of flooding: Presentation of the operational planning and preparation of municipal fire departments. Explanation of the factor time in emergency response and situation assessment."* *"Operational tactics in disaster control:*

		Presentation of the structures and tasks of disaster control in Germany and at district level. Explanation of general fire department tactics and possible procedures in the event of unexpected flooding.” *“Wish for active exchange and expert consultations between districts and SH3”* *“Separation of tasks: SH3 monitors the water levels in the Erft catchment area, the German Weather Service (DWD) warns of precipitation events”* *“Outlook: exchange with municipalities regarding alarm and emergency plans”* *“Involvement of municipalities: Find municipal representatives (one per district) with whom an exchange can take place “*
	Position of the organisation and interconnectedness with other systems	
	Institutional capacities for analysing the environment	*“Data: the required data is available in a usable form; professional consulting and/or discussion is required; in case of an extreme event this* ***cannot be ensured for every district control center in terms of personnel capacities****; therefore, this is aimed for in advance”* *“What can SH3 do: Provide information and offer technical support even without being part of the official warning and reporting chain (e.g. HOWIS training courses);* ***Situation center*** *in the event of an incident at the SH3 so that contact officers of the municipalities can be reached (instead of sending employees of SH3 in the municipalities;* ***saves personnel resources*** *of SH3* ***)”***

		Communication and collaboration with others (diversity of information)	*"Data: the required data is available in a usable form"* *"What can SH3 do:* ***Provide information*** *and offer technical support even without being part of the official warning and reporting chain (e.g. HOWIS training courses)"*
		Scientific approach to data collection, analysis and priorisation	*"Can HOWIS-system in its current state help the stakeholders? What (additional) data and information would be beneficial? How does the data need to be prepared in order to be used efficiently?"* *"Hydrological assessment of a situation by employees of SH3 requested"* *"Data: the required data is available in a usable form;* ***professional consulting and/or discussion is required"*** *(e.g. HOWIS training courses)* *"Situation assessment: an introduction to HOWIS is required"* *Internal Meeting SH3: Where can we go?: "Provision of discharge forecasts and assistance in dealing with and interpreting uncertainties"; "Linking the situation assessment with flood hazard maps, which scenario (HQhäufig, HQ100, HQextrem) the situation comes closest to. This will encourage the districts to actively engage with the* ***flood hazard maps****"*
		Environment scanning for weak / early warning signals	
Step 2	Develop scenarios, considering ongoing and potential future transitions.	Develop scenarios of future developments (alternative futures), including low probability scenarios	*"extreme scenarios: scenarios for the case of overflow or dam failure required"* *"Simulation of events is already working well"* *"Simulation game for a flood event"*

		Potential future transitions	*"damage potentials: will also be determined within the intermunicipal flood protection corporation (FPC) for non-risk water bodies in the catchment area of SH3"*
Step 3	Determine goals and the level of tolerability for risk and uncertainty.	Short-, Medium- and long-term goals	*"Built uniform shared awareness"*
		Business or economic goals	
		Normative goals	*"situation assessment: more intense exchange of information between stakeholders and SH3 required in order to improve the assessment of certain situations (in terms of weather forecast); ways of communication need to be identified and set"* *"Finding possible interfaces between operational flood protection, research and practice* *"What does SH3 achieve with the project: contribute to the improvement of risk management together with stakeholders in DRM and water management; not only research results, but concrete findings for the improvement of the current situation at the local level"*
		Tolerability for risk and uncertainty	*"damage potentials: will also be determined within the intermunicipal flood protection corporation (FPC) for non-risk water bodies in the catchment area of the SH3"*
Step 4	Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation,	Co-develop solutions with other actors	*"idea: implementation of online meetings with districts and hydrologists from SH3 to discuss the situation of e.g. heavy rain forecast"* *"Involvement of municipalities:* ***Find municipal representatives*** *(one per district) with whom an exchange can take place; Districts could organize events with the*

and to navigate the transition.		*municipalities at which SH3 presents DIRECTED"* *"What can SH3 do:* ***Provide information*** *and offer technical support even without being part of the official warning and reporting chain (e.g. HOWIS training courses)"* *"expected outcome: development of improvement strategies for risk governance focusing on flood protection, possible contributions of SH3; districts are the link to the federal state"* *"Further procedure of DIRECTED Project: build a network, constant exchange, involve project partners with different expertise"*
	Build resilience – encourage self-organisation	*"Population: Must be sensitized to the issue of flooding; Must be better informed about which water level of a water body corresponds to which water level at their place of residence; Raise awareness that not only water but also the movement of water and the carrying of objects poses a danger"* *"Introduction of the flood information and warning system Erft (HOWIS): including the development, the basics as well as the provision of information in the online portal."* *"SH3: Workshop series with the districts to improve/practice the use of HOWIS (flood information system) and the interpretation of the information provided to the districts"*
	Prepare for disruptions, accidents, crises	*"Communication: During the 2021 flood, communication between the fire departments and SH3 was good as long as telephony was still possible → Find a solution for*

			communication in disaster situations"
		Address scenarios from step 2 (with a list of management strategies)	*"extreme scenarios: scenarios for the case of overflow or dam failure required which serve as the basis for operational plans for evacuating areas below the dam"* *"Simulation of events is already working well"* *"Simulation game for a flood event"*
Step 5	Address unanticipated barriers and sudden critical shifts that may come up during the process.	deliberative exercises to identify and overcome barriers	*Further procedure of DIRECTED Project: "build a network; identify problems, obstacles, needs etc."* *"challenges and difficulties need to be identified first, hence an in-person meeting at the SH3 is planned"* *"topics identified: communication; data (HOWIS)"* *"data: the required data is available in a usable form; professional consulting and/or discussion is required"* *"Introduction of the HOWIS Erft, including the development, the basics as well as the provision of information in the online portal."* *"Introduction of the further education and training programs of the working group. Introduction to the newly founded regional disaster control network for the accomplishment of major floods and heavy rain events (H-Kat-Net)."*
		All involved stakeholders prepared and legitimised to overcome barriers	*"Introduction of the flood information and warning system Erft (HOWIS): including the development, the basics as well as the provision of information in the online portal."*
		Transparency, agility, openness to innovation (to overcome barriers)	*"control of flood protection basins: information on the commissioning, filling level etc. which SH3 forwards to the district government in Cologne will from*

			now on also forwarded to the districts"
Step 6	Decide, test and implement strategies.	Compare the strategy options developed in steps 4 and 5	
		Test and experiment strategies	*Internal SH3 meeting: "transition from pre-warning level to warning level in HOWIS, in the test phase the hydrological situation report of the LANUV should serve as a trigger"* *"in the DIRECTED project: Implementation of simulation games, analysis and lessons-learned to develop the interface with the district"* *"This situation assessment should be tested and practiced within DIRECTED"*
		decide which strategies to implement	
		Clear and transparent decision-making criteria	
		Involve all stakeholders in decision-making	
Step 7	Monitor, learn from implementation, review and adapt.	Regular monitoring of the strategies	
		Learn from implementation	
		Review and adapt	
		Flexibility through adjustment loops and iterative processes	