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Catchment, Streams and Sewers

Strengthening Flood Resilience in Bonn

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Abstract

The City of Bonn has experienced flooding on several occasions in the past. However, in the last two decades, it has seen increased precipitation leading to floods. The City had initiated several flood management measures in response. Those measures played a significant role in minimizing the impact of the heavy rainfall seen in July 2021. With this report, the Bonn Water Network (BWN) documents the successful efforts of the City of Bonn administration and the catchment authorities in responding to the floods. The report is also part of BWN's effort to strengthen cross-learning, co-produce knowledge and build a true partnership with the City of Bonn. The report documents the authorities' adaptive response and the challenges encountered by both civil society and the respective authorities in taking resilient action. It draws on secondary documents and online resources, which are supplemented with interviews with city authorities and experts. The report was presented to the city authorities with a request for their feedback, which subsequently flowed into its finalisation.

The report highlights the steps taken by the authorities towards flood mitigation, flood preparedness and flood response. Those measures are described at three levels – catchment, streams and sewers – as looked at from a social, technical and legislative perspective. To gain an insight into how these initiatives converge, the report uses the example of flood risk management at the level of local streams. Given the various institutions involved in the City's flood management activities, it identifies the challenges faced by three key actors in implementing flood management measures. The report concludes with an outlook that shows a way forward by highlighting the need to strengthen the hybrid infrastructure approach in order to secure a sustainable strategy. It identifies opportunities for use in strengthening risk management and mitigation in respect of pluvial flooding, promoting hybrid governance and utilizing both science-policy dialogue and digitalization in strengthening flood risk management in Bonn.

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Abbreviations

BauGB	Building Code
BBK	Federal Office of Civil Protection & Disaster Assistance
BUND	Bund für Umwelt und Naturschutz Deutschland (Friends of the Earth Germany)
BWN	Bonn Water Network
EU	European Union
FFF	Fridays for Future
FRMD	European Flood Risk Management Directive
HKC	HochwasserKompetenzCentrum
HWRM	Flood Risk Management Plan
ICPR	International Commission for Protection of the Rhine (ICPR)
LANUV	State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia
LWKG	Act on the Establishment of the Chamber of Agriculture of North Rhine-Westphalia
LWG	Landeswassergesetz
MULNV	Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia
NRW	North Rhine-Westphalia
SDG	Sustainable Development Goals
WFD	EU Water Framework Directive

1 Introduction

Extreme weather and climatic events are impacting cities worldwide. Floods with catastrophic effects, such as those seen in North Rhine-Westphalia, Germany, in July 2021, are attributed to climate change (Evers et al., 2021). The floods took the lives of 170 people and damaged properties and the environment (Schleussner et al., 2021). Record-setting precipitation of up to 182 mm of rainfall within 72 hours triggered severe floods in the region. With incessant rain and extreme weather events linked to climate change (Norwegian Meteorological Institute, 2013), cities are strongly focusing on approaches and techniques to become more resilient to urban flooding. A large portion of the City of Bonn's catchment is located in the Middle-Rhine basin, while a smaller portion is located in the lower Rhine basin. In the 19th Century, the city experienced flooding mainly caused by ice melt and snowfall, with water levels in the Rhine River rising to 10 metres (Appendix 1). In the 20th Century, floods caused the water level to rise to around nine metres along the riverbank. In the 21st Century, however, flooding during summer rains has increased, with severe weather events seen in 2010, 2013 and 2016. All of these, and especially the flood in 2013, played a significant role in the Federal Government's reorientation towards integrated flood risk management in Germany (Thomas & Knüppe, 2016). Despite the heavy rainfall experienced in the city at the time, the July 2021 flooding in North Rhine-Westphalia had only minimal impact in Bonn.

This report attempts to document the successful approach to flooding adopted by the City of Bonn administration and the catchment authorities. The City of Bonn is an international hub for sustainable development and is part of the Global Network of Learning Cities to accelerate the Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in 2015. It has repeatedly showcased its ability to design policies and implement sustainable strategies. The Bonn Water Network (BWN) is a consortium¹ of 11 institutions specialized in water-related research, both in Germany and worldwide. It brings together internationally renowned scholars and consolidates their expertise. The report promotes cross-learning, the aim being to co-produce knowledge and build a true partnership between BWN and the City of Bonn.

The report documents the adaptive response shown by the various authorities and also the challenges faced, both by civil society and the authorities involved, in adopting a resilient approach. It draws on secondary documents and online resources. These are supplemented with interviews with City authorities and experts. The report was presented to the city authorities with a request for feedback, which subsequently flowed into its finalisation.

¹ The Bonn Water Network (<http://www.bonnwaternetz.de/>) consists of 11 renowned institutions with longstanding experience in water management and related issues: the *Bonn International Center for Conversion* (BICC), *Bonn University* with its *Institute of Geography* (GIUB) holding the UNESCO Chair in Human Water Systems, the *Center for Development Research* (ZEF) and the *Institute for Hygiene and Public Health* (IHPH), the *German Development Institute / Deutsches Institut für Entwicklungspolitik* (DIE), the IUCN Environmental Law Centre, and three Bonn-based UN institutions – the *United Nations Institute for Environment and Human Security* (UNU-EHS), the *Secretariat of the United Nations Convention to Combat Desertification* (UNCCD) and the *Global Water Operators Partnerships Alliance* (UN-Habitat/GWOPA). In addition, the Berlin-based *Water Integrity Network* (WIN) is a partner of the BWN.

The following section describes the integrated flood risk management efforts in the Rhine river basin and those of the city authorities. The second section highlights the steps taken by the authorities towards flood mitigation, flood preparedness and flood response. These measures are described at three levels – catchment, streams and sewers – when looked at from a social, technical and legislative perspective. The third section takes a left tributary of the Rhine – the Mehlemer Bach stream – as a case in point to highlight how these efforts converge and are synchronized at the level of streams. The fourth section identifies the roles and responsibilities of key actors responsible for flood management in Bonn. The fifth section examines the roles of the three key actors – civil society, the city administration and local policymakers – in making Bonn resilient in its flood management approach. The report concludes with an outlook that shows a way forward by highlighting a shift towards a hybrid infrastructure approach in order to secure a sustainable strategy and identifies opportunities in strengthening flood risk management in Bonn.

2 Integrated flood risk management in the City of Bonn and its catchment area

Bonn is connected to the Alps and the North Sea by the flowing waters of the Rhine. Spanning across Italy, Austria, Liechtenstein, Switzerland, France, Germany, Luxembourg, and the Netherlands, the Rhine river basin is home to approximately 60 million people and one of the most important economic, industrial and trade regions in Europe. During the 18th and 19th Centuries, the Rhine was subject to a series of river works, including the construction of dams, dikes and locks to facilitate navigation and trade. The development and industrialization of cities like Ludwigshafen, Mannheim, Frankfurt, Cologne, the Ruhr conurbation and Rotterdam were possible thanks to their Rhine location. But these economic benefits came at a cost, primarily the alteration of the river's natural course, the degradation of its ecosystems and the increased risk of floods (Nollkaemper, 1996). From the 1960s and over a period of some 40 years, several cooperation agreements were signed by participating states to address pollution and floods in the Rhine river, most notably:

- The Convention on the International Commission for the Protection of the Rhine against Pollution (Berne, 29 April 1963)
- The Convention on the Protection of the Rhine against Chemical Pollution (Bonn, 3 December 1976)
- The Convention on the Protection of the Rhine against Pollution with Chlorides (Bonn, 3 December 1976)
- The Convention on the Protection of the Rhine (Berne, 12 April 1999)

2.1 Transboundary flood management framework

In 1950, considering the challenges facing the Rhine and based largely on good faith, Switzerland, France, Germany, Luxembourg and the Netherlands established the International Commission for the Protection of the Rhine (ICPR). The first measure adopted by the ICPR focused mainly on reducing and preventing pollution (Wieriks & Schulte-Wulwer-Leidig, 1997). During the 1970s and 1980s, the ICPR developed measures to

reduce municipal and industrial wastewater discharges into the river and construct wastewater treatment plants, which progressively improved the quality of the Rhine water (Wieriks & Schulte-Wulver-Leidig, 1997). During this time, the countries sharing the Rhine river basin also negotiated and adopted crucial instruments, including the Convention on the Protection of the Rhine against Chemical Pollution and the Convention on the Protection of the Rhine against Pollution with Chlorides – both signed in 1976 in Bonn.

Cooperation against pollution: In 1986, a fire in a warehouse near Basel, Switzerland, resulted in the discharge of large amounts of toxic chemicals into the Rhine, devastating the river's aquatic life (Schwabach, 1989). This incident mobilized an immediate response to enhance the management of and cooperation in the Rhine basin. The result was the adoption of the 1987 Rhine Action Programme, with three main objectives to be reached by 2000:

- To improve the Rhine ecosystems to such an extent that native species, such as salmon and sea trout, again become indigenous.
- To guarantee the production of drinking water from the Rhine for the future.
- To reduce the pollution of river sediments to the extent that at any time, sludge can be used for landfills or be dumped at sea.

Cooperation against floods: In 1993 and 1995, severe floods affected the middle and lower Rhine regions. Based on the lessons learned with Rhine Action Programme, the Conference of Rhine Ministers developed an “Action Plan on Floods”. The plan had the following targets:

- To reduce damage risks by 25% by 2020.
- To reduce flood levels by up to 90 cm by 2020.
- To increase flood awareness by drafting risk maps for 100% of the areas at risk of flooding.
- To improve the flood forecasting system through international cooperation.

In 2015, the Flood Risk Management Plan replaced the targets adopted under the Action Plan on Floods by focusing on:

- The avoidance of new unacceptable risks.
- Reducing the existing threats to an acceptable level.
- Reducing the adverse consequences during floods.
- Removing the adverse effects after a flood.

According to the Assessment Rhine 2020 report (ICPR, 2020), most of the Action Plan of Floods targets have been achieved at a cost of approximately €14 billion. The achievements included the reduction of flood damage risks by 25% by 2020, heightened awareness among the population following the publication of flood risk maps and improved flood warning announcement systems.

Legal instruments applicable to flood management

In 1999, France, Germany, Luxembourg, the Netherlands, Switzerland and the European Union signed the Convention on the Protection of the Rhine. The scope of the Convention encompasses the Rhine River, the groundwater interacting with the Rhine, the aquatic and terrestrial ecosystems, the pollution affecting the river and flood prevention and protection along the river course (ICPR, 1999). At European level, the European Parliament and the European Council adopted the Water Framework Directive in 2000, which included provisions on mitigating the effects of floods. Adoption of the European Floods Directive followed in 2007. Establishing a framework for use in assessing and managing flood risks, its aim was to reduce the adverse consequences for human health, the environment, cultural heritage, and economic activity associated with floods in the EU.

Rhine 2040 programme

At the 16th Conference of Rhine Ministers held in Amsterdam in 2020, the Rhine 2040 Programme was adopted with the aim of creating a sustainably managed Rhine catchment area that is resilient to the effects of climate change, with valuable lifelines created for nature and people. The Programme set the target of mitigating flood risks by at least 15% on the Rhine and its tributaries by 2040 compared to 2020.

Specific goals on flood risk mitigation include:

- To update the flood information, forecast, and warning systems and undertake adequate training. In addition, the nations and federal states/regions continue to support each other in the event of a flood.
- To implement measures to reduce flood levels planned for 2020+ by 2030.
- To plan and secure spaces for flood retention on the Rhine and its tributaries planned for 2030.
- To synergize measures to improve flood protection and the ecological situation on the Rhine and its tributaries.
- To keep undeveloped flood areas free of structural development.
- To adapt new buildings to the flood risks in flood-prone areas and, where applicable, also existing buildings (building precautions).
- To strengthen awareness of flood risks through information sharing and training.

2.2 Flood mitigation measures

Flood mitigation measures aim to reduce the likelihood and magnitude of flooding and complement flood defences. They reduce the overall risk of experiencing flood damage and lessen its severity when it occurs. Triggered by the floods in 1993, 1995 and 2013, the State of North-Rhine Westphalia (NRW) and the City of Bonn have taken enormous efforts towards flood mitigation with a combination of structural and non-structural measures. To

protect some 1.4 million people living in the catchment and its ecosystem, the North Rhine-Westphalia (NRW) Chamber of Agriculture has implemented a number of measures to ensure flood mitigation at the levels of catchment, streams and sewers. These mitigation measures are intended to reduce or even eliminate the risk of flooding before it occurs (Landwirtschaftskammer, 2021a).

NRW draws on the EU and the German Federal Government’s framework for context-specific interventions in the Middle-Rhine and Lower-Rhine Catchment area, where Bonn is a landmark city. NRW prepares its Flood Risk Management Plan for six-year periods (the first to third cycles covering 2010-2015, 2016-2021 and 2022-2027). Before their finalization, the plans are made available to the public for comment. The input received is discussed and incorporated into the plans by the respective district administrations and sectoral actors before being implemented to minimize flood risks in the region. Focusing on catchment, streams and sewers, the authorities approach flood management in the catchment area with a mix of flood protection and flood risk management measures (Thomas &Knüppe, 2016).

The city administration and the regional authorities have introduced a combination of structural and non-structural measures (Table 1). The structural measures include dikes, flood plain management, retention ponds, green roofing and other courses of action that divert water away from people and communities. The measures, implemented at catchment, stream, sewer and urban residence level, are supplemented with community initiatives and related legislation. In each of these, measures were adopted ranging from flood risk area zoning, flood prevention, regeneration following flood events and coping with flood events, combining awareness creation and legislative changes. This synchronized action in the catchment-stream-sewer networks across socio-technical legislation marks a shift towards integrated flood risk management.

Phase	Scale	Structural measures	Community initiative	Legislation
<i>Flood mitigation</i>	Catchment	Catchment zoning (Zone I, II, and III)	About 700 protection committees	Water protection area ordinance
	Streams and flood plains	<ul style="list-style-type: none"> • Dike rehabilitation and construction • Bulwark • Flood protection • Grids and rakes in streams 	<ul style="list-style-type: none"> • Precautionary warnings • Flood partnership 	State Water Act to provide permits for buildings
	Sewers	Ensure functionality of existing sewers	KommNetAbwasser	NRW Ordinance on self-monitoring of sewerage systems
	Early warning	<ul style="list-style-type: none"> • Monitor water level • Soil moisture • Snow cover 	n/a	n/a
	Urban settlement	<ul style="list-style-type: none"> • Porous pavements • Blue-green roofs • Rain gardens 	n/a	German Building Code
Source: Authors				

2.2.1 Catchment management measures

The catchment region is monitored and regulated by the District Government of Cologne, both as the Upper Water Authority and the point of contact in the areas of water management and water protection (Bezirksregierung Köln, 2021). The goals and tasks of the District Government of Cologne include implementation of the European Flood Risk Management Directive (FRMD) and definition of flood plains in the Rhine and Sieg rivers. Division 5 of Cologne District Government is responsible for nature and landscape protection, technical, environmental protection and operational and technical occupational safety. Within this Division, Department 54 (Water Management, including plant-related environmental protection) is closely linked to flood protection and management (Bezirksregierung Köln, 2021). The Department draws up management plans and flood risk management plans for the administrative district in accordance with the provisions of the Federal Water Resources Act 2009 (as amended in 2021), the Water Act for the State of North Rhine-Westphalia 2022 (Landeswassergesetz (LWG)) and the EU Water Framework Directive. These plans summarize measures for improving water quality, water ecology and measures for flood prevention and flood protection. They form the basis for the water management-related decisions of the Ministry for the Environment, Nature Conservation and Consumer Protection of the State of North Rhine-Westphalia. The authorities prepare the Flood Management Plan for different river basins in NRW.

In addition, the authority approves and supervises the construction and operation of dams, wastewater treatment plants, private and public water supply facilities, and flood protection and water restoration measures. It also decides on water use abstraction, monitoring abstraction activities in cooperation with the State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV).

The District Government of Cologne approves both the construction and substantial modification of flood protection systems on the waters of the Rhine, Sieg, Agger, Wupper, Rur, Erft and Niers rivers. For matters concerning water maintenance, water expansion and water restoration, it is also responsible for the Sieg river from the state border with Rhineland-Palatinate to the mouth of the Rhine. Catchment protection is established to manage water, ensure it remains free from contamination and reduce excess drainage (Landwirtschaftskammer, 2021a). Many forest and agricultural areas are located within this water protection area, which abides by the measures designed to protect it from flooding. Broadly speaking, it covers the entire catchment of drinking water extraction plants and is divided into three zones with different protection regulations: (i) Frame range, (ii) Narrower protected areas and (iii) Other protected areas (Landwirtschaftskammer, 2021b).

- (1) Frame range (Zone I): This zone protects the immediate vicinity of the drum plant from any contamination. With the exception of dams, it is very small and only accessible to the operator of the extraction plant. In this zone, apart from the maintenance of extraction equipment, virtually all other activities are prohibited. In the case of drinking water reservoirs, Zone I generally covers the entire body of water with a riparian strip.
- (2) Narrower protection zones (Zone II): The zone is intended to ensure protection against contamination by pathogenic microorganisms and other dangerous impairments within a short flow time downstream or to the extraction plant, e.g. intensive grazing is prohibited. In the case of groundwater protection areas, the boundary of Zone II corresponds to the

so-called 50-day line, i.e. the groundwater takes 50 days to arrive at the collection plant from this line. This minimum travel time ensures that pathogens are largely eliminated. In the case of a dam, Zone II is designated along the above-ground tributaries.

- (3) Other protection zone (Zone III): The zone is intended to protect against far-reaching impairments, particularly by chemical or radioactive contamination that is not degradable. For example, systems used in storing scrap vehicles and other scrap are prohibited. Different rules also apply where untreated and treated rainwater is concerned. Zone III covers, where possible, the entire water catchment area and is divided into sub-zones III A and III B.

The Lower Rhine Catchment has over 700 water protection areas covering more than 550,000 ha (Landwirtschaftskammer, 2021b). The district governments and authorities determine the protected areas managed by means of community-based cooperation. The ordinances containing the protected area-specific prohibition and approval provisions are published in the respective official gazettes and are valid indefinitely. However, the competent authority may limit the regulation. The lower water authorities are responsible for compliance with Water Protection Area Ordinance provisions.

Triggered by the floods of the Century in 1993 and 1995, the state of NRW has been planning a total of eleven large retention areas on the Lower Rhine since 1996 (Landwirtschaftskammer, 2021c). These are intended to retain around 170 million m³ of water during floods over an area of about 5,000 hectares used almost in their entirety for agriculture. These plans are associated with huge financial investment and only lower the flood peak by about 10 cm. They also raise fears of an existential threat to farms. To avoid this threat, the authorities are considering lowering foreland areas. These measures can lower the flood peak by about 15 cm, which is to be welcomed from both an agricultural and a local residents' perspective. Retention basins should be planned as fully controlled pocket polders, which can be opened at the most favourable time when needed and are not used as uncontrolled flood polders with a congestion frequency of up to twice per year (including regular agricultural damage). Based on these considerations, the Lohrwardt polder was converted to a controlled variant, achieving flood relief for the lower lying areas – including the Netherlands.

Protection via cooperation areas: Since 1989, farmers, gardeners and water supply companies have cooperated to manage the protection areas based on the 12-point programme of 27 June 1989 (Landwirtschaftskammer, 2021d). The 12-point programmes are agreed between the Chambers of Agriculture and the North Rhine-Westphalian associations of agriculture, water management and horticulture. The Cooperative Water Protection Committee works closely with farming communities via consultation and support measures. These combine water management, land management and agricultural activities to protect the environment in the catchment. The cooperation activities depend on the natural conditions, particularly the geological and hydrogeological conditions, the nature of the soil, the agricultural structures and prevailing water quality. The activities include applying fertilizers, water-friendly cultivation systems, erosion protection, avoidance of direct substance inputs, information and public relations.

The cooperation areas show measurable successes. The strength of the cooperation model speaks for itself. This is reflected in the intensive, trust-based cooperation seen between all

parties involved over the years, providing a basis on which to tackle problems and solve them. The cooperation model also further develops and adapts to meet new conditions.

2.2.2 Stream and flood plain management on the Rhine river

The City of Bonn implemented structural measures ranging from dike rehabilitation and construction, to storm water management and flood plain protection along the streams and flood plains of the Rhine River (Bundesstadt Bonn, 2021a).

Dike rehabilitation and construction: Historically, people living on the Lower Rhine have joined forces to form dike associations for some 700 years or more (Landwirtschaftskammer (NRW) (2021c). The City of Bonn has been constructing and rehabilitating dikes in the Beuel-Nord area and along the banks of the Rhine. Mobile flood protection dikes further prevent flooding behind the barrier (Appendix 2 – Dike Rehabilitation in Beuel-Nord). The mobile flood protection measures can be put up at any time and dismantled without leaving residue behind. The new system is not only cheaper compared to dikes, with estimated costs of at least €460,000 net in 2006, but also offers other advantages such as fast and easy handling, low follow-up costs, easy dismantling, variable construction, durability, low-cost storage and low susceptibility to vandalism. A mobile flood protection system is intended to prevent extreme Rhine floods of up to eleven meters high from overflowing into Bonn's lowlands.

Second bulwark against Rhine flooding: Due to increased investment in recent decades, the Rhine promenade in Beuel is now relatively well equipped against medium-height floods should the river burst its banks. This kind of protection against a sudden rise in water levels during extreme floods was lacking in the lower rear Altrheinarm (old arm) areas (from Ramersdorf via Konrad-Adenauer-Platz to Schwarzrheindorf). The first section of this second line of defence behind the protective structures on the promenade adjoins an extension of the Rhine. In an emergency, mobile protection dikes are used here, for which devices for floor anchoring were built several years ago. This improved the level of protection, raising it from the existing 10.55 metres to cope with flood waters reaching eleven metres in height.

Flood protection at the Endenicher Bach: Between 1961 and 2004, there were repeated floods in the centre of the Endenich district in Bonn (Bundesstadt Bonn, 2021b). The small stream known as the Endenicher Bach overflowed its banks several times, causing considerable damage. The stream was renaturalized, expanded and partially closed off at a cost of some €755,000 following a decision of the Bonn district council in 2007. In the 1960s, the open stretch of the stream in Pastoratsgasse was connected using too narrow a pipe, which resulted in it overflowing. The City of Bonn eliminated this bottleneck in 2006 with the construction of a flood relief canal of about 150 metres long, laid at a depth of five to eight metres and measuring 1.40 metres in diameter. This helped to drain relatively small amounts of water on Pastoratsgasse, with the rest draining through the relief channel. Draining is controlled via a throttle valve.

New grid reduces the risk of flooding: The City of Bonn placed grids at the inlet to reduce the risk of clogging in the stream. First and foremost, the metal grid is used for safety to protect children playing by the stream from falling into the canal. It also prevents the channel from clogging due to alluvial material that might block floodwater and cause it to

back up. Unfortunately, the piece of grid previously installed there had been so severely damaged in the heavy rain event on 29 and 30 July 2014 that it could no longer be repaired. The civil engineering office has since developed a different construction that is clogged less quickly by alluvial material and is both easier and safer to open in an emergency.

New rake can be swivelled inwards: The decisive advantage of the new rake is that the lower part can now be swivelled inwards and is no longer turned only against the water pressure as before. In addition, the fire brigade and the Federal Agency for Technical Relief staff deployed in an emergency can open the device safely from the bridge. This, too, has not been possible so far. Another advantage is that the rake's rods are no longer vertically but horizontally attached. In this way, alluvial material, which is unable to cause blockages or damage in the stream's canal pipe, can then flow off safely. The new grid measures 3.50 metres by 80 centimetres and costs around €2,700 – a worthwhile investment given the otherwise potential damage.

Early warning measures: The Rhine catchment area has several small streams, which can swell dramatically within a short space of time due to intense precipitation and snowmelt. Having water level gauges in a small catchment area for centimetre-accurate and time-accurate water level predictions is difficult due to heavy rainfall and the short length of time between the rain event and the rise in the water level. Therefore, instead of level-related flood forecasts, region-specific flood warnings are used which take account of the soil moisture level and any existing snow cover, along with weather-related forecasts. This can indicate a real flood hazard earlier than solely observing water levels. A comprehensive water balance model calculates the flood warnings and is based on the flood risk zone maps. The flood warning maps give an overview of the extent of the flood at a water level of 10 metres and identify resources at the appropriate level. The flood warning also takes into account the above-ground inflow of flooding, premature leakage of groundwater in cellars and low-lying areas, and blockages in sewer networks. Flood pumping stations in Beuel and Mehlem ensured the regular operation of the sewage system in some areas, even in the event of flooding to a level of 9.50 metres. Bonn's flood-prone areas include Mehlem, the Beuel waterfront and the Rathenauufer stretch (between the streets Erster and Zweite Fährgasse). The waterfront promenade at the Alter Zoll (a bastion at the site of the former customs house) floods when water levels reach 7.50 metres (the waterfront road at 8 metres). When flooding occurs, the district of Graurheindorf is also affected. If flooding is expected, precautionary warnings are issued to households in the area involved (Appendix 3).

For buildings located in flood-prone areas, it is recommended that the building advice (Appendix 4) provided by the City of Bonn Building Regulations Office be considered before planning a construction project (Bundesstadt Bonn, 2021a). As part of that advice, it can be determined whether the construction plot is located in the natural or planned legal flood plain and if a permit is required under the NRW State Water Act and must be applied for from the offices of the State Agency for Nature, Environment and Consumer Protection (LANUV) in Cologne.

2.2.3 Sewer management

Urban drainage systems play an essential role in the management of water. "Urban drainage systems comprise all infrastructures for the management of wastewater and rainwater in the

built environment” (European Standard EN 752, cited in Bossler et al., 2021). These infrastructures consist of wastewater and stormwater sewers, open space, road, fire, water bodies, gas and electric lines, and other infrastructure. Catchment and stream management often receive attention during floods, while urban infrastructure systems go unnoticed. Urban drainage flooding or sewer flooding is caused when a drain or sewer becomes full due to heavy rain and blockage, resulting in overflows inside a property or outside in the garden, the street or public spaces. To withstand unpredictable disruption, these systems are regularly maintained. During floods, they require ‘rapid and appropriate action’ (Bossler et al., 2021, p. 3).

The municipal wastewater unit is part of the Municipal Wastewater Network (KomNetABWASSER), an initiative of currently around 80 wastewater companies in North Rhine-Westphalia. The network “aims to implement the municipal wastewater disposal mandate better and in a more citizen-friendly way” (KommNetAbwasser & IKT, 2021). It focuses on sewer operation, flood prevention, property drainage and quality assurance in sewer rehabilitation. The companies perform tasks according to the NRW Ordinance on self-monitoring of sewerage systems. Successful prevention of heavy rainfall runoff is based on the ordinance and successful operation of its provisions (Bosseler et al., 2021). The task of the companies in the network is to take regular action to protect, manage and maintain existing infrastructure. During flooding they work to restore the functionality of the drainage network.

2.2.4 Urban settlement

The measures at the catchment, stream and sewers level is supplemented with efforts at private household scale. These measures include encouraging porous flooring in residential buildings, promoting green roofs and rainwater harvesting structures under Germany’s Federal Building Code.

2.3 Flood preparedness

Flood preparedness equips Bonn with the infrastructure and precautionary measures needed to deal with impending floods (Bundesstadt Bonn, 2021c). The City has introduced a package of measures in public infrastructure and has devised a flood preparedness plan containing a range of preventive procedures. Various departments, including the volunteer fire brigade, the fire and rescue services, the civil engineering office and other stakeholders, hold flood preparedness events in affected areas, such as along the Mehlemer Bach. These measures, which involve the organization of prompt and efficient response and rehabilitation, are taken to reduce to the absolute minimum the loss of human lives and damage caused. Preparedness in the city authorities includes: (1) triggering of early warning measures by the fire brigade and designating areas for relief activities, (2) sewer management companies assess and develop action plans to clear blockages in sewers, prioritize vulnerable locations and designate infrastructure points for relief measures, (3) clearing debris and streets to avoid blockage, and (4) creating alternative transport networks.

Phase	Scale	Structural measures	Community initiative	Legislation
<i>Flood preparedness</i>	Regional scale	<ul style="list-style-type: none"> • Early warning measures • Areas for relief activities 	<ul style="list-style-type: none"> • Fire brigade • Building Regulations Office • The Lower Water and Waste Management Authority 	n/a
	Sewers	<ul style="list-style-type: none"> • Share responsibility • Assess risks • Develop action plans 	KommNetAbwasser	NRW Ordinance on self-monitoring of sewage systems
	Urban Settlement	<ul style="list-style-type: none"> • Building protection • Waste disposal, street cleaning • Deployment of relief activities • Activating rainwater harvesting structures 	Fire Brigade	German Building Code

Source: Authors

Flood warning

In an impending flood, the fire brigade triggers the siren alarm, publishes the information in the NINA warning app and broadcasts announcements via local radio stations. Depending on the location of a localized heavy rain event in the catchment area, “warning times” of between ten and 90 minutes can be achieved, enough to enable people to reach a safe location. Local residents are provided with useful tips that they can use to protect their buildings (Appendix 3). Extensive protective measures at the Edenich and Mehlem streams (addressed in more detail in the following section) have reduced the risk of flooding, thus preventing potential damage. As the water rises during a flood, residents have their work cut out to prevent the worst of the damage in the time that is left. The Building Regulations Office and the Lower Water and Waste Management Authority provide precautionary guidelines to help residents (Appendix 4) protect their property and homes. This helps them avoid flood damage. This is followed by relief deployment and coordination activities. Coordination of relief activities takes place via the fire brigade command centres, with helplines set up in incident rooms. When calling the helpline numbers, residents are asked if they require the fire brigade, police or other time-critical emergency services.

Sewer management

With the threat of imminent flooding, the wastewater companies use the hazard warning map to decide on the precautionary measures needed (KommNetAbwasser, IKT, 2021). The measures include (1) sharing responsibilities, (2) assessing risks and (3) developing action plans. Sharing responsibilities includes clarifying the division of responsibilities with other actors, sharing information between departments and conducting plausibility checks. In addition, the companies and other stakeholders assess risks to prioritize vulnerable locations

and infrastructure points, identify emergency response rescue routes and inform citizens using leaflets and other measures.

Waste disposal and street cleaning

Before an impending flood, all waste containers are to be emptied (Bundesstadt Bonn, 2021c). Depending on the location, “bonnorange”, the company responsible for solid waste management, also removes empty waste containers and takes them into temporary storage. Before the onset of the flood season, bulky waste is picked up from unscheduled streets. Bulky waste containers are also set up at certain points as needed. Local households are informed about the dates and locations by loudspeaker announcements and on the bonnorange website. Where necessary, yellow bins and bags for recyclable materials are emptied in good time before the flood arrives. The large street-located containers for waste glass and waste paper are moved to flood-free areas. After the flood, bonnorange strives to remove flood-related bulky waste and debris as quickly as possible, and to clean the streets of mud and sludge.

Operation of alternative transport networks

Boats from various aid organizations are used to enable access to homes that are flooded. The residents themselves are responsible for enabling entry to individual plots. Boats are used to evacuate people in flooded roads, hourly during the day and, if necessary, more frequently at night – every two hours if possible.

Bonn has beautiful cycle paths that lead directly along the banks of the Rhine. However, when the river overflows, they become partially flooded. On the left bank, the cycle paths are completely flooded from a water level of 6.50 metres. On the right bank, this happens at a water level of 7.50 metres. Detour signs are posted to ensure that cyclists still reach their destination safely, with dry feet (and wheels). The diversion leads away from the Rhine onto a signposted cycle route that runs parallel to the path along the Rhine and leads to Bonn’s southern boundary.

2.4 Flood response and recovery measures

The City of Bonn administration and the regional authorities spearhead measures immediately after floods to restore both the city and its activities (Bundesstadt Bonn, 2021c). Broadly speaking, the restoration measures are taken at city, sewer network and private household scale.

Phase	Scale	Structural measures	Community initiative	Legislation
<i>Flood response</i>	City	<ul style="list-style-type: none"> • Pumping out water • Addressing groundwater hazard • Collection of flood debris 	<ul style="list-style-type: none"> • Fire brigade • bonnorange 	n/a
	Sewers	Restoring network functionality	<ul style="list-style-type: none"> • Sewer operators • KommNetAbwasser 	n/a
	Private households/ Fire brigade	<ul style="list-style-type: none"> • Pumping of water • Collection of flood debris 	Local residents	n/a

Source: Authors

Pumping out water: When the water recedes after the flood, the city authorities and local residents pump out excess water from cellars and rooms. The fire brigade does not provide pumps to pump out water during the flooding phase. Only after the water has receded does the Fire Brigade – within the scope of its possibilities – help to pump out cellars and other rooms. It is vital that residents be warned against pumping out water too early, because the pressure of the groundwater rising up under the basement and against its exterior walls can cause extensive building damage.

Groundwater hazard: When water levels are high, the groundwater rises accordingly, endangering buildings and facilities in areas further away from the Rhine. Even when floodwater drops, the groundwater continues to rise for a certain period of time. It is therefore suggested that residents check their basement rooms more often than they usually would and take precautionary measures. In such cases, pumping out the groundwater too early can lead to building damage. Residents are thus advised to:

- Open the backflow valves of their building’s drainage system in good time so that the water can drain off.
- Place flood-related bulky waste on the roadside or in the containers set up as required.
- bonnorange disposes of any debris washed up at property by flooding. This also applies to sludge.

3 Stream water management in Mehlem

The floods seen in western Germany in July 2021 have shown the catastrophic consequences of heavy rainfall and underline the need for flood protection measures in the face of extreme weather events in Germany (Evers et al., 2021). The streams in the area of the City of Bonn – among them the Mehlemer Bach, the Godesberger Bach, the Hartbach and the Katzenlochbach – are sensitive to heavy rainfall events due to the topography of the catchment connected to the Rhine terraces on the river’s left bank. The Mehlemer Bach, located in the south of Bonn, has witnessed several floods since 2010, each causing severe damage to infrastructure and buildings. This has led to flood protection measures being implemented

in Mehlem, successfully preventing damage during the heavy rainfall event in July 2021. Seen as a best-practice example of integrated flood risk management they include structural measures, an early warning system and risk communication. This combination of flood protection measures was also recognized by the Flood Competence Center (HKC) as crucial in coping with heavy rainfall events (Evers et al., 2021).

3.1 Flood events at the Mehlemer Bach since 2010

The Mehlemer Bach, with its catchment of 18.3km², flows from the Municipality of Wachtberg to Mehlem, a district in the south of Bonn, before draining into the Rhine (Box 1). Combined with the area's steep topography, the unpredictable local weather conditions in its catchment are potentially dangerous. For example, small-scale thunderstorms lead to heavy rainfall in the higher catchment while weather conditions in the lower catchment remain good. The risk of flash floods occurring in a short space of time is high.

Box 1: Profile Mehlemer Bach
Source: Confluence of the Züllinghovener Bach and Berkumer Bach in Oberbachem
Mouth: At 664,07 km on the Rhine
Size of the catchment: 18.3 km ²
Length: 4,830 m
Course: 2,730 m of the Mehlemer Bach are located in the area belonging to the Municipality of Wachtberg. Of these, 2,100 m are located in the area of the City of Bonn, of which 450 m flows in concrete pipes.
Condition: “The water body is classified as “heavily modified” from the mouth to about Stat. 1.23 with respect to the WFD.” (Bundesstadt Bonn, 2008, App. p.2).
Classification by the district government 2009: Risk/hazard waters (in German “Risikogewässer”)
Flood events since 2010: 2010, 2013, 2014, 2016, 2021
Source: Bundesstadt Bonn (2008)

In the Municipality of Wachtberg, the main risk of flooded infrastructure and buildings along the Mehlemer Bach occurs in Werthoven and along the banks of the stream in Niederbachem (Bezirksregierung Köln, 2019). Downhill, in Bonn-Mehlem, the water from the upstream catchment of the Mehlemer Bach accumulates before it reaches the Rhine. In the densely populated centre of Mehlem, the stream flows open, passing under several bridges. On its final stretch, the water is directed to a pipe beneath the surface (Fig. 1, image 10). This channel through the centre of Mehlem harbours a high risk of flash floods.

As a result of the heavy rain events in 2010, 2013 and 2016, and combined with the topography of the watershed, the stream exceeded the capacity of its streambed, resulting in significant flooding. The stream overflowed its banks and the piped section was unable to drain the excessive volume of water. The pipe inlet located at Mainzer Straße (Fig. 1, image 10) was flooded and the stream's water fanned out in the lower reaches of the

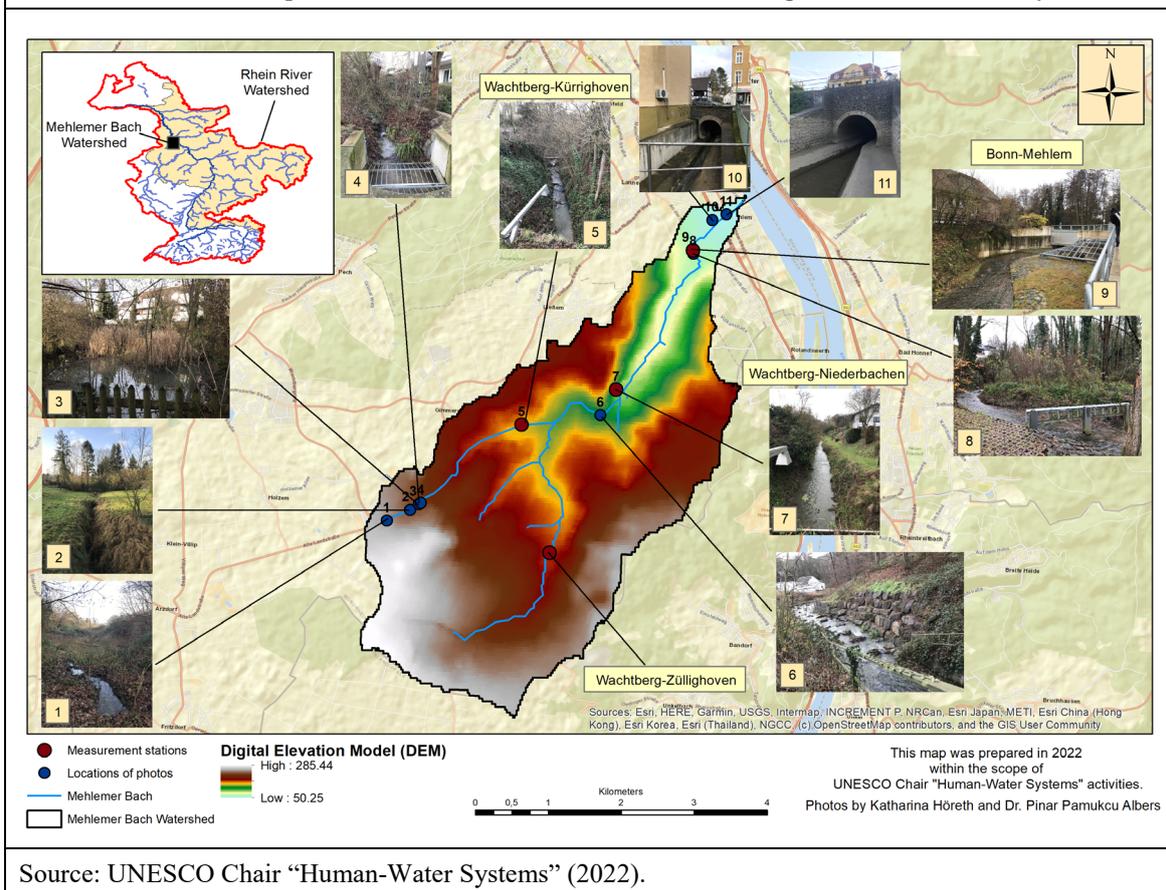
catchment area. 2010 and 2013 buildings and crucial infrastructure like the main road and local shops were affected by the flood (Bundesstadt Bonn, 2022a; Blesel, 2010).

The City of Bonn had undertaken a series of flood protection measures since 2010, ranging from structural flood prevention, setting up an early warning system and raising awareness among residents to prevent a flood in July 2021. The measures taken are described below.

3.2 Structural measures

A wide range of structural measures have been implemented in the lower catchment of the Mehlemer Bach. During the flood in 2010, the Rhine river outlet of the Mehlemer Bach was washed away and had to be restored (Fig. 2, image 11). The stream had collapsed once before, during the flood in 1931 (Bundesstadt Bonn, 2022a). In 2013, the construction of a bypass was considered to provide relief from extreme flood events. Renovation of the existing stream channel took place in 2014 (MULNV and Bezirksregierung Köln, 2021).

Figure 1: Map of the Mehlemer Bach showing the elevation of the watershed, including impressions of the status quo and structural measures introduced along the stream in January 2022



Source: UNESCO Chair “Human-Water Systems” (2022).

In 2015, the civil engineering department of the City of Bonn started to construct the bypass. The bypass inlet is located at Bachemer Straße in Bonn Mehlem (Fig. 2, image 9). Its concrete pipe of 1,050 m in length and with a diameter of DN 3000 relieves the original streambed when the water reaches a certain level, directing inflow under the nearby railway tracks, the B9 road and Drachenstein Park, straight into the Rhine (Bundesstadt Bonn, 2016).

The bypass was completed at a cost of about €12 million in 2019 (Bundesstadt Bonn, 2022a). During the heavy rainfall event in July 2021, the bypass safely led the water masses from the streambed into the Rhine and prevented severe flooding in the stream mouth area of the Mehlemer Bach. Only one pedestrian underpass was flooded – it lies at the same water level as the stream. In 2022 and 2023, the section of the stream running from the B9 road to the Rhine is scheduled to be expanded even further to protect the surrounding structures (Bundesstadt Bonn, 2022a). The capacity of the bypass exceeded the volume of water from the heavy rainfall in July 2021 (Mühlens & Königs, 2021). The inlet is equipped with a steel bracing construction to protect the bypass from blockage (Fig. 2, image 9). Additionally, a steel rake has been installed around 30 metres upstream of the bypass inlet (Fig. 2, image 8) and is anchored in the ground to prevent floating debris from reaching the bypass entrance. Rakes have also been installed at the stream's upper streambed (Fig. 2, image 4) to reduce hydraulic damage from floating material (Bundesstadt Bonn, 2022a).

The implementation roadmap for Bonn's water bodies was adopted in 2012. In cooperation with the City of Bonn, the Municipality of Wachtberg and the Rhine-Sieg District, a consulting firm drew up a map with detailed measures for the Mehlemer Bach. The roadmap focuses on implementation of longer-term environmental measures in line with the EU Water Framework Directive (WFD). Environmentally compatible watercourse maintenance is aimed for along the entire length of the stream. The concept also includes structural measures (Fig. 2, image 6). There are plans to deconstruct and inspect transverse structures, and to optimize sections where needed (Bundesstadt Bonn et al., 2012). It is intended to widen various sections of the channel and to remove the bed and bank stabilization. Development of a self-dynamic secondary floodplain is also part of the planned measures, is the extensification of the stream's use and keeping the floodplain free from buildings and infrastructural activities (Fig. 1, images 1, 2 and 3).

The removal of larger, woody plant species that are not typical for the stream's location has already taken place. Maintenance measures are carried out on an ongoing basis, with perennial neophytes such as hawkweed or *Hercules* perennial being cut back or the roots being dug up (Bundesstadt Bonn, 2022a). Many of these measures also serve flood protection.

3.3 Early warning and risk communication

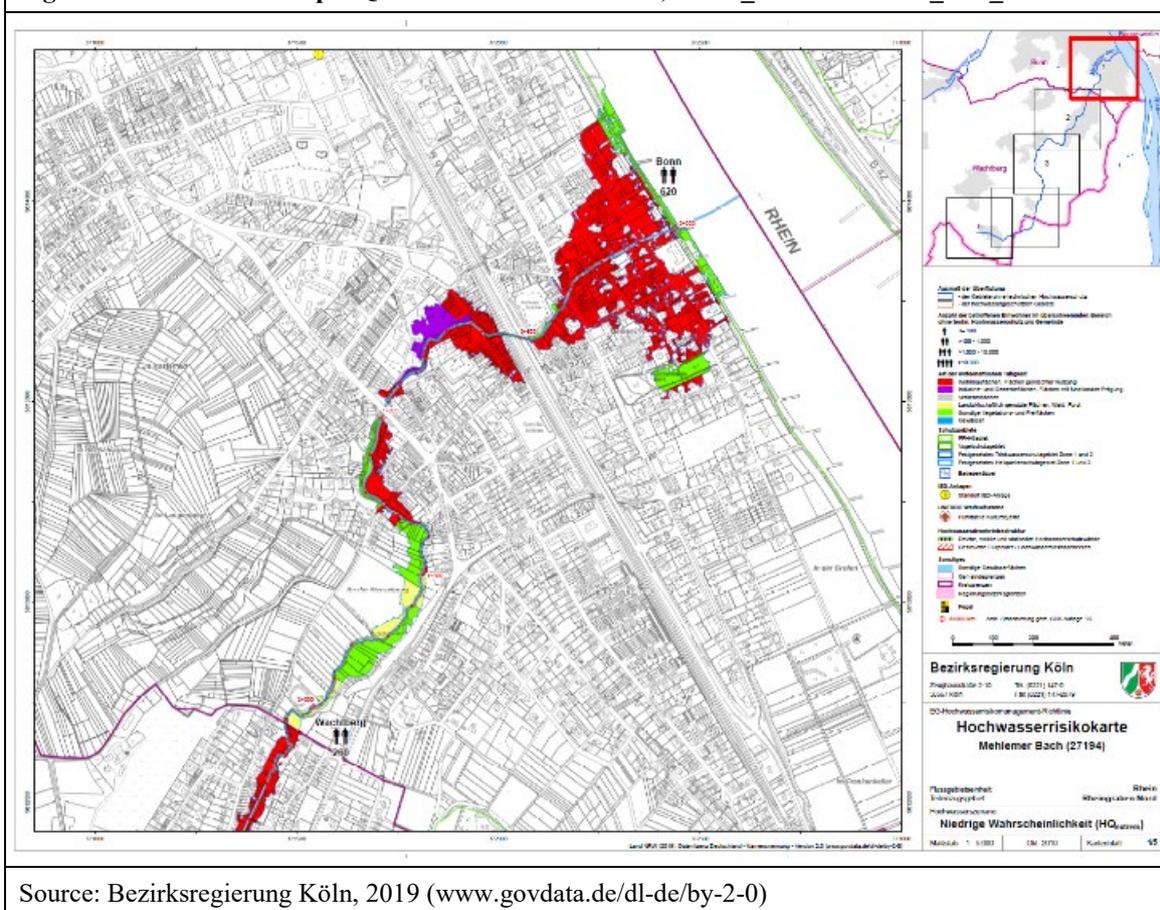
The flood hazard and risk map is the primary document used in communicating flood risk and in implementing flood protection measures in Mehlem. The Cologne District Government is responsible for preparing flood hazard and flood risk maps in accordance with the EU Flood Risk Management Directive (FRMD) (Bezirksregierung Köln, 2019). According to the flood risk maps drawn up for various flood scenarios, depending on the recurrence probability of a 10-year (HQ_{10}), a 100-year (HQ_{100}) or an extreme flood event (HQ_{extreme}) (see HQ_{extreme} in Fig. 2), fan-shaped flooding in the mouth of the Mehlemer Bach is predicted. Critical infrastructure like the main road, shops and schools are located at vulnerable spots as are residential buildings (Bezirksregierung Köln, 2019).

Following the flood events at the Mehlemer Bach in 2010 and 2013, the Municipality of Wachtberg and the City of Bonn entered into a "flood partnership" (in German "Hochwasserpartnerschaft"). The partnership represents a significant contribution to flood

protection in the entire catchment as it enables joint investigation of the flood situation and provides a collective strategy for flood protection measures along the Mehlemer Bach (MULNV & Bezirksregierung Köln, 2021). This includes collecting data to show the flood emergence area and implementing a system for early warning. It also builds awareness of flood risk among residents in both Wachtberg and Bonn.

The early warning system for the Mehlemer Bach is based on data on precipitation and the water level in the stream. In 2014, a precipitation measuring station with real-time transmission was jointly installed by the Municipality of Wachtberg and the City of Bonn to enhance the provision of local warnings. Data from the Municipality of Wachtberg was transferred to the Bonn fire brigade command centre’s early warning system.

Figure 2: Flood risk map HQextreme Mehlemer Bach, 27194_MehlemerBach_A00_B001



Source: Bezirksregierung Köln, 2019 (www.govdata.de/dl-de/by-2-0)

In spring 2017, the civil engineering department of the City of Bonn installed water level measuring stations with zero-contact radar technology along the Mehlemer Bach, located at places like bridges, where valid data regarding the water level was already available. An automatic warning system has also been introduced that permanently monitors the stream levels (Fig. 1, images 5, 7 and 9) and, where necessary, sends messages to the fire brigade command centre and the on-call services of the civil engineering department in Bonn. Additionally, video surveillance of the watercourse is provided to visually verify the plausibility of transmitted warnings and data (Esch & Walther, 2018).

This information is immediately transferred to warn residents without delay. The fire brigade command centres set off sirens to draw people’s attention to the situation and can

also make announcements on local radio. The “NINA” warning app operated by the Federal Office of Civil Protection and Disaster Assistance (BBK) is another communication channel used for timely warning of impending floods. The overall system enables early warnings ranging from 10 to 90 minutes (Esch & Walther, 2018).

While the early warning system is vital, it must go hand in hand with awareness-raising efforts. Residents have to know how to react in the event of an emergency and be able to prepare themselves long before a flash flood occurs. This is where the main challenge lies – in ensuring that residents are well informed about the flood risk and the measures they should take to protect themselves, that they are informed in a timely way in the event of an emergency and that they know how to act in the risk situation concerned.

The key lies in the range of information material prepared and made available both online and in print, such as in flyers and on City of Bonn website. Online material includes flood risk maps and local weather forecasts. Since 2014, Bonn has offered information and advice on water and building law issues. Upon request, residents can receive information on planning law relating to their properties and their location in the floodplain (MULNV & Bezirksregierung Köln, 2021).

Special priority is given to flood protection measures for residents. In the joint campaign, “Bonn unterstützt” (which roughly translates to Support for Residents in Bonn) (HKC & Bundesstadt Bonn, 2022), the City of Bonn in conjunction with the HKC provides residents with information on the flood risk concerning their homes and other buildings to ensure they are aware of the risk of flooding in the future. The City administration provides an initial risk assessment within a 10-minute window using an online questionnaire asking about the location of the building and features like whether it has a basement and the level at which the door is placed. The result shows whether the building is at risk from river flooding and/or flooding due to heavy rainfall events. The website also suggests consulting an expert for a fee to obtain a detailed evaluation. This gives residents the opportunity to obtain a flood pass. Holders of a flood pass have a sound risk assessment of their building and welcome suggestions on reducing the risk of flooding. The City of Bonn provides detailed information on its website, for example on installing backwater protection and effective drainage.

4 Flood risk management: key agencies’ roles and responsibilities

Both within the City of Bonn administration and elsewhere, there are a number of departments that jointly manage floods.

State level organizations

The Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia (MULNV) (<https://www.umwelt.nrw.de/>) is an arm of the State Government of North Rhine-Westphalia. The Ministry applies Federal, Länder-level (state) and EU laws, oversees their implementation and controls the entire process via a variety of executive agencies. It enact laws and plays a significant role in federal-level law-making. The Ministry plans and prepares bills that are then submitted to the state legislature for parliamentary deliberation and enactment. One of the Ministry’s core

activities is the preparation of the Flood Risk Management Plans (HWRM) for the Rhine, Maas, Ems and Weser river basin districts in NRW. The plans are valid for six years (periods for the first to third cycles cover 2010-2015, 2016-2021 and 2022-2027) and are regularly updated.

The State Office for Nature, Environment and Consumer Protection North Rhine-Westphalia (LANUV) (<https://www.lanuv.nrw.de/>) is a scientific and technical authority of the State of North Rhine-Westphalia. Its mandate includes nature conservation and landscape management, fisheries ecology, air pollution control and water protection, noise and vibrations, soil protection and contaminated site detection, waste management and plant safety, environmental medicine, environmental analysis, food and feed monitoring, animal welfare and animal disease control. It also operates the North Rhine-Westphalia air quality monitoring system and maintains its own laboratory ship, the Max Prüss, to monitor the water quality of the rivers and canals in North Rhine-Westphalia. In addition, it specifies the number and type of samples from the areas of food, consumer goods and veterinary monitoring that are examined and assessed by the chemical and veterinary inspection offices.

The Chamber of Agriculture of North Rhine-Westphalia has the task of promoting and supervising agriculture and those working in it, and of strengthening rural areas. As part of the Act on the Establishment of the Chamber of Agriculture of North Rhine-Westphalia (Chamber of Agriculture Act (LWKG)), the list of tasks under the Act includes promoting economic efficiency, environmental compatibility and consumer protection of agricultural production through appropriate facilities and measures, capacity-building for young professionals and employees, offering advisory support, promoting sustainable agriculture and engaging in international cooperation for sustainable agriculture. The task of the Chamber of Agriculture is both to ensure effective flood protection of farms and land and to work towards moderate contributions by farms to local flood protection effort.

City level organizations

The Department of Planning, Environment, and Transport (Department III) is an umbrella organization in the City of Bonn that is responsible for various tasks related to the planning and construction of structures, public spaces, wastewater disposal and flood protection. The Department also approves building applications, water law, emission control and nature conservation. Department III offices involved in flood risk management include:

The Office for the Environment and Urban Green Spaces maintains and develops a total of 651 hectares of public green and play areas as well as cemeteries, including around 100,000 urban trees as a vital resource for humans, animals and plants. The municipal forest covers an area of 600 hectares and is managed according to the guidelines of Naturland e.V. In addition to the planning, construction and maintenance of Bonn's urban greenery, the Office also includes cemetery development and burial services.

The Building Regulations Office performs tasks of the Lower Building Supervisory Authority in accordance with the North Rhine-Westphalia State Building Code. Its mandate includes examining building applications, ensuring compliance at construction sites, taking measures to avert danger (for example, floods) and providing advice and support.

The **Tiefbauamt** is the civil engineering office involved in the construction and maintenance of urban roads and urban drainage in Bonn. This includes 1,200 km of public roads, over 300 traffic lights, about 950 km of canals with unique structures, four sewage treatment plants, streams and bridges. With regard to flood management, the Tiefbauamt ensures safe collection, discharge and treatment of Bonn's wastewater along a 950 km sewer network and at four sewage treatment plants. It also maintains and controls water bodies in the urban area (127 km of streams). In conjunction with the Office for the Environment and Urban Greenery, it also maintains and controls the banks of the Rhine, including measures to improve flood protection and prevent the damaging consequences of heavy rainfall events. The two bodies also supervise and monitor a number of private companies employed for water and sewage management. The Tiefbauamt operates and/or participates in nationwide monitoring of wastewater quality (including detection of corona viruses).

The **Fire Brigade (Fire and Rescue Service)**. Bonn City Council is required by law to provide, equip and maintain an efficient Fire and Rescue Service. The Fire and Rescue Service is responsible for fire suppression and for providing assistance in all kinds of emergencies. It also works to prevent fire and minimize its effects. Preparing for disaster and disaster management is also the responsibility of the fire and rescue service. In addition to full time staff, the fire brigade has over 500 volunteer members to provide rapid response assistance in emergencies of all kinds. They also perform specialist roles (e.g. HAZMAT defence, communications, setting up casualty treatment areas, catering for operational units, flood control and lighting). During protracted incidents, some volunteer units will provide cover at full-time fire stations.

As part of a private-public partnership, **bonnorange** – the municipal waste management service provider, performs urban cleaning and waste management in Bonn. It cleans streets, squares and other public spaces, empties waste bins and containers, picks up bulky waste and keeps roads clear in winter. When flooding occurs, it plays a crucial role both before and after the event, clearing away waste bins and containers, and cleaning streets. They also ensure correct disposal of used clothing, electrical appliances and valuable and harmful substances. bonnorange also operates an online portal where residents can give away or exchange items they no longer need, thereby contributing to waste prevention and resource conservation.

Non-governmental organizations (NGOs)

Friends of the Earth Germany (BUND), a national NGO, acts as a driving force for sustainable development in Germany and is one of the largest environmental associations in the country. They are committed to ecological agriculture and healthy food, to climate protection, expansion of renewable energy use and protection of endangered species. They work closely with the democratic decision-making structures at local, regional and national level.

Fridays for Future (FFF) is a youth-led, youth-organized global climate strike movement that started in August 2018. It was sparked by Greta Thunberg, who started a school strike to raise awareness to the need for climate protection. The goal of the movement is to raise awareness on climate policy abuses and climate justice as well as to demand action from policy-makers, calling on them to listen to scientists and implement solutions to limit global warming.

These organizations, along with civil society and private companies, play a crucial role in addressing the flood risk situation in Bonn. A key feature of effective city-level institutions is their *resilience*: the ability to cope with and bounce back from crisis or disaster without systemic collapse. Resilience is the capacity to prevent, mitigate and/or respond effectively to shocks (World Bank, 2019).

5 Institutional resilience in flood risk management

Institutional resilience is more pertinent today than ever before, especially in the city of Bonn, because it focuses on the ability to learn from past flood events and improve flood mitigation, preparedness, response, and recovery. This section identifies the key actors involved in climate resilience and flood management in Bonn, setting out the factors that can influence their actions. The factors presented are inspired by the results of Sanger’s (2021) master’s thesis, in which she conducted empirical research on the topic of factors that influence urban planners’ behaviour towards green infrastructure for climate change adaptation in Bonn. Those results help to identify both drivers of and barriers to climate resilience and flood management in the city of Bonn. From those drivers and barriers, the measures needed to improve the city’s resilience can be derived. Three major actors – civil society, local policymakers, and the city of Bonn administration – are identified as having significant influence on Bonn’s climate resilience and flood management approach (Fig. 3).

Figure 3: Actors in integrated flood risk management



Source: Authors

5.1 Civil society

Civil society is the first and one of the most influential actors in climate resilience and flood management in Bonn. While civil society initiatives such as FFF, the Transition Town Initiative and urban gardening movements have emerged since the heatwave in summer 2018, the Green Party's victory in Bonn's 2020 local elections show that civil society can and does drive change. These recent developments reflect the fact that addressing climate issues in public discourse is increasingly desired. This makes civil society a key driver of change, influencing both urban planning and flood management decisions and actions.

However, in matters of flood resilience, civil society is not always a driving factor. For example, people are not always willing to accept flood management measures in their neighbourhood if they appear to pose a threat to their personal interests. This is a phenomenon referred to as "NIMBYism", meaning not-in-my-backyard. Such behaviour can have a severe negative impact on the city's climate resilience if someone lodges a complaint or opposes a flood management measure on their property. In such cases, people give priority to their own interests rather than to furthering the common good.

5.2 Local policymakers

Local policymakers influencing climate resilience and flood management in Bonn through local-level policymaking. Local policy ranges from Bonn City Council decisions, to laws and regulations at district, state, and federal level. As municipalities in Germany are responsible for deciding and managing their planning agendas, local institutions are empowered to make decisions on measures designed to enhance climate resilience and flood management activities. A case in point is the city council's decision to develop solutions to prevent future flooding at the Mehlemer Bach, a watercourse particularly vulnerable to flooding in the past. In this case, Bonn's civil engineering department responded to this prevention policy mandate by proposing the construction of a Mehlemer Bach bypass.

Laws, regulations and other planning instruments influence both climate resilience and flood management. Environmental concerns are anchored in the Building Code (BauGB), which provides the legal basis for urban planning at the federal level in Germany (Süßbauer, 2016). Since amendments in 2011 and 2013 in the BauGB, issues of climate change adaptation have either been legally anchored in article 6 or specified as objectives and principles of urban land use planning (Albrecht, 2019). Alongside the BauGB, urban land use planning is the most important instrument in influencing climate resilience. For example, climate change adaptation measures can be integrated into land use plans and development plans through the implementation of green infrastructures (Langhagen-Rohrbach, 2010). Furthermore, informal instruments such as extreme precipitation and flood hazard maps are considered in both land use plans (for example, to determine which areas can be designated for which uses) and development plans. Such maps are an important tool in achieving climate change adaptation via development plans and zoning plans in construction projects, identifying adaptation needs for new and existing uses, and civil society consultations and information (Roggema, 2009; Süßbauer, 2016).

The designation of floodplains (which is the responsibility of the District Government of Cologne) is another formal instrument used to ensure that floodplains are kept free from

development. Another relatively new formal instrument involves extreme precipitation and flood reports. These are required by the civil engineering office to protect buildings from extreme weather events. One legal problem that often occurs, especially with regulations that have only recently come into being, is that they only apply to new development plans. This is despite the fact that there are many existing developments for which there are no regulations governing subsequent implementation of flood protection measures.

The timescale is another problem that makes it difficult to implement planned measures. Measures should have an immediate impact, but spatial planning and urban development are processes planned far in advance. The implementation phase takes time, which means that what is planned now will not be implemented for another five to fifteen years or more, and the effects will only be seen thereafter.

5.3 City administration

The city of Bonn administration is another major actor that influences the city's climate resilience and flood management approach. It has clear hierarchical structures, meaning that power is distributed across different departments, positions and people, making it an important influencing factor in matters concerning climate resilience. In addition to the mayor, who heads the city administration and therefore has the power to potentially influence climate resilience, the department heads, who are elected independently of the city parliament, are also powerful people, as they perform their duties independently of the mayor. Thus, there is not just one, but several influential individuals in a city administration whose interests need not necessarily coincide. City administrations thus function like a hierarchical pyramid that starts with the mayor at the top, then spreads out into the individual departments and extends down to the various offices and subdivisions. Those individuals in a city administration who specifically work to enhance Bonn's climate resilience are often located at the bottom of the pyramid, thus limiting both their ability and their capacity to promote their related interests.

The roles and responsibilities of the city administration is spread across different subject areas, which is why cooperation and communication between the different departments and offices play a crucial role. Climate resilience is a cross-cutting issue that is touched on in many different departments and offices. A good communication structure among those departments and offices is essential for addressing climate resilience-related issues. However, in order to improve climate resilience in Bonn, city administration offices will have to cooperate with other offices outside of their respective mandates.

Due to overlapping roles and responsibilities, urban planning decisions are often hampered by conflicts of interest. As there are many different offices in an administration, their interests are correspondingly diverse. Also, each office collaborates within its own area of expertise, leading to conflicts of interest between both offices and colleagues in every planning process. The compromises that have to be made within the various offices do not always contribute to climate resilience in Bonn. In fact, climate resilience concerns are only one aspect of city administration and urban planning, and they are not classified as an issue of primary interest.

6 Moving towards hybrid infrastructure-based flood risk management

“Decisive action by all social powers is a prerequisite for overcoming the challenges posed by the climate crisis in Bonn.” Mayor Katja Dörner (Bundesstadt Bonn, 2021e)

A mission statement published in 2019 announced a comprehensive municipal sustainability strategy with the sole aim of developing Bonn as a climate-resilient city and reducing its vulnerability to climate change. The city of Bonn has been involved in transitioning to a climate-resilient city since the mid-1990s. With its current population of approximately 330,000 projected to increase by 12.1% by 2040 (Bundesstadt Bonn 2020a; 2021), Bonn is and will continue to be faced with increasing urban development and surface sealing (Sandholz et al., 2021). At the same time, the city is striving to address the inevitable consequences of climate change through adaptive planning that addresses the urban climate situation. It has implemented numerous projects to adapt infrastructure to the climate change effects of heavy rainfall and floods. Since the first extreme weather event experienced in the recent past, the floods in 2010, a whole package of climate adaptation measures for Bonn has been initiated – starting with establishing an early warning system for stream floods and extensive structural measures which include the provision of advice for residents and optimization of operational processes (Bundesstadt Bonn, 2022b).

The City of Bonn has adopted a hybrid approach that combines engineering or grey, green and blue infrastructure to address extreme precipitation and flooding. As part of the “Green Funding” programme, this approach combines green roofs and facades on existing buildings, installation of grass and riparian buffers, urban trees, stream restoration, wetland restoration, and restored ecosystems. While the hybrid approach is still at too early a stage to allow evaluation, it harbours potential to balance traditionally built infrastructure with more nature-based solutions, especially when it comes to improving management of urban water, heat, and other climate-driven threats (Depietri & McPhearson, 2017). Sängler (2021) references several authors who consider such approaches to be a cost-effective, multifunctional solution that contributes to hydrological regulation and flood protection, while also pursuing a whole range of other goals. These include regulating the microclimate, promoting biodiversity, improving people’s health and well-being, enhancing social cohesion, fostering job creation, and contributing to the aesthetics of our urban environment, thereby promoting a sustainable economy (Gill et al., 2007, Farrugia et al., 2013, Matthews et al., 2015, Elmqvist et al., 2015, EC, 2019, Geneletti et al., 2020).

The City of Bonn’s Climate Emergency Declaration announced in 2019 was a significant step towards hybrid, infrastructure-based flood risk management. The declaration has given rise to a catalogue of measures with recommendations for action on climate change mitigation and climate change adaptation, complete with funding (€5 million) allocated for a period of two years (Bundesstadt Bonn, 2020c). With the recent political shift towards the Green Party in autumn 2020, Bonn’s policy priorities may also shift more towards climate-related topics (Sängler, 2021). Despite the significance of the city’s effort in handling flood risk, pluvial flooding remains a real challenge. Pluvial flooding occurs when precipitation intensity exceeds the capacity of natural and engineered drainage systems (Rosenzweig et al., 2018). The intensity is expected to increase throughout the course of the 21st Century. Bonn has been preparing for these challenges. As part of its “Bonn Unter” campaign, the city collaborates with the Flood Competence Center (HKC) to inform residents in Bonn, advising them to take

precautions against floods and heavy rain damage (Bundesstadt Bonn, 2020b). Despite these measures to address the growing challenges, there are a range of opportunities available that can help to reinforce the city's role in flood risk management. These include:

Understanding pluvial flooding (Rosenzweig et al., 2018)

- Map the adaptation tipping points (threshold beyond the magnitude of impacts of climate change such that management practices cannot cope)
- Enhance understanding of the water cycle in ultra-urban areas (current modelling considers only hydrological process studies and observational data, but not the effects on as-built subterranean drainage infrastructure).
- Examine the multifunctionality of hybrid infrastructures.

Hybrid governance

- Transboundary and cross-sectoral coordination is fundamental in ensuring coherent actions (Thicken et al., 2016).
- Develop understanding and models on the potential impacts of extreme events at different levels – catchment, streams and sewer networks for preparedness and possible responses.
- Municipalities have a key role in implementing plans at a local level.
- Build local and regional capacities for hybrid infrastructure.
- Create an enabling investment environment through the involvement of private and public stakeholders for adaptation to hybrid infrastructure. This should be supported by adequate quantification of the adaptation benefits to be had from the related investments.
- Climate resilience should be prioritized across city administration departments and other institutions.

Science-policy dialogue

- Advance science-policy dialogue for planning and implementation based on informed decisions.
- Management plans need to be designed, adopted and implemented at different scales.
- Public acceptance and trust-building among actors.
- Make disaster risk zones wide and clear in urban planning and building guidelines.

Digitalization and financial opportunities

- Enhance opportunities for digital transformation.
- Create an enabling investment environment to enable adoption of hybrid infrastructure.

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Appendix

Appendix 1: Water level rise during major flooding in Bonn		
Floods		
Water levels		
cm	Date	Rank
1020	28.11.1882	1
1013	23.12.1993	2
1010	01.01.1926	3
1006	30.01.1995	4
998	16.01.1920	5
955	01.01.1883	6
950	24.02.1970	7
945	29.05.1983	8
943	29.03.1988	9
935	19.01.1955	10

Source: Bundesstadt Bonn (2021)

Appendix 2: Dike rehabilitation

The dike rehabilitation Beuel-Nord (Combahnstraße to junction Beuel Nord) was completed in 2011. The dike is now designed for a level of 11.18 meters. The upstream flood protection up to 9.50 meters Bonn gauge along the Rhine promenade, from Werdstraße via Marienstraße to Ernst-Moritz-Arndt-Straße, was created in two planning approval sections, each with five construction phases between 1993 and 2011. The compensatory measure for the loss of retention space by the Beuel “Promenadendeich” took place on the Rheindorfer Bach in 2001. The first construction phase for the second line of defense (Professor-Neu-Allee) has been completed. The second line of defence is required to secure the level of protection (now 11.20 metres) from an undercurrent, which was increased by one metre during the rehabilitation of the Beuel-Nord dike. A mobile wall in the middle of the street prevents the flooding behind the dike, which otherwise occurs from 10.10 meters via Combahnstraße. In order to avoid underground pathways via the sewage system, the construction of a second canal was necessary. For the second construction phase of the second defensive line (Hermannstraße/Agnesstraße), the purchase of a mobile floodwall closed the existing gap in protection against suddenly penetrating water into the lowlands to Schwarzhindorf and Limperich. An overflow in the area of Friedrich-Breuer-Straße into the Beuel lowlands takes place here from about 10.70 meters. The Siegdeich was completely renewed in 1993 and, like the Rhine dike Beuel Nord, protects up to a level of 11.20 meters.

Appendix 3: Guidelines for households preparedness for floods

Some hints should help to think of everything as much as possible:

- Evacuation of cellars, garages and other parts of the building threatened by flooding.
- Provision of waste containers and bulky waste for special collection.
- Inspection of the house drainage system and backflow valves in the basement.
- Protection of heating systems (for example, decommissioning, removing burners).
- Remove your motor vehicle from the garage, sidewalk, parking space or street in good time before the flood comes.
- Please pay attention to the roadblocks and parking bans.
- If, in individual cases, you have to drive into the restricted area to salvage or secure property, be sure to leave your accessibility clearly visible behind the windshield. This allows us to inform you before any necessary towing measures.
- Park your vehicle in safe places outside the flood area.
- Prepare makeshift connections between upper floors and roads through ladders, trestles and planks.
- Make arrangements in case your wired phone fails.
- Have a white cloth or a flashlight or warning light ready for the night time in order to be able to make yourself felt from the window by visual signs if you need help.

Finally, an urgent request: Help sick neighbors in need of help and care or pass on appropriate information to the local helpers.

Appendix 4: Recommendations and information by the Building Regulations Office and the Lower Water and Waste Management Authority (Office for the Environment and Urban Greens)

- In the case of new buildings, the ground floor is to be arranged 0.5 metres above the high water mark of December 1993 (10.13 metres Bonn gauge).
- Rooms below the flood mark must have openings for flooding or be constructed to be buoyancy-proof by structural measures. The staff of the Building Regulations Office (Building Statistics) will be happy to advise you.
- In the construction of buildings in flood-prone areas, a so-called “flood floor” is usually not counted towards the number of floors (GFZ) or, if it is to be regarded as a full flood under building law and the permissible use is exceeded, a dispensation is granted. It is strongly discouraged to set up living quarters on these floors. For flood times, an “emergency exit/emergency exit” should be planned.
- Buildings in flood-prone areas should preferably be equipped with gas as an energy source.

If an oil firing system cannot be dispensed with at all, special attention must be paid to the heating oil storage tank. The following points must be observed:

- The heating oil storage tank shall be secured against ceilings and walls by means of vertical and horizontal struts in such a way that the tank is prevented from drifting during flooding.
- All tank openings to the level indicator and limit value transmitter must be sealed in such a way that no water can penetrate from the outside.