PERC Flood event review ‘Bernd’

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What's inside

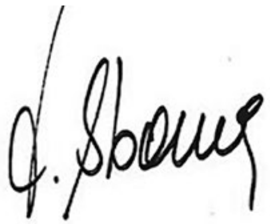
Foreword

Weather system "Bernd" caused immense damage and inconceivable human suffering in several European countries in July 2021, and struck the West of Germany, but also Belgium, Luxemburg, and the Netherlands particularly hard. The physical and also psychological recovery will take years if not decades and will require and hopefully stimulate change towards prioritizing resilience at all levels, from the personal to the local and communal administrational levels all the way up to national and international policy. Change is urgently needed – how we think and implement flood risk management and civil protection.

This event was by far our largest and most complex PERC analysis of the over 25 studies conducted globally in the last decade. We typically conduct these investigations at the event level and use a holistic approach. However, with this flood it is difficult to even properly define or grasp this situation as one event. There were several flood events that we found - the focus was primarily on the Ahr Valley, which was very badly affected, as well as the affected urban communities further north such as Erftstadt, Euskirchen and Eschweiler, as well as communities and regions in the Netherlands, Luxembourg and above all the Walloon region of Belgium, for which floods of this scale are rather unusual in summer. Our team has contacted hundreds of stakeholders with countless emails and on-site discussions in order to work out the insights from this event - or these events - which had different consequences. One constant that has come up again and again is the keyword "unimaginable". For the population now so badly affected, it was unimaginable, even knowing about recent floods like 2016, which were described as major, that an event of the magnitude of 2021 could even happen. For the technical experts and their derivation of flood statistics it was inconceivable that such an event apparently had to be classified very "far in the extreme range in the flood distribution curve. For the emergency services, the pictures of the destruction, well the "Situation picture" was unimaginable, and then, how one should deal with it in the immediate chaos phase of the first few days. For those directly affected, it was and probably remains unimaginable what suffering and what destruction could come over them. And even for our team, even after many days of field visits almost a year after the floods, it remains unimaginable to a certain extent what exactly happened that night.

Still, this is an attempt to make the unimaginable somehow tangible. An attempt to analyze, what kind of early warning people now, after the event, expect, and what kind of early warning the available data, the structure of the civil protection services, and the political will even allow. We want to better describe which measures for recovery, building forward and to implement risk reduction are currently being taken up, and which ones the population would like to see. One thing is clear, the willingness to help and the will to work together is great. People have moved closer together in the affected areas, we have been told this again and again, and they stand together. The term "SolidAHRity" was coined in the Ahr valley. Nevertheless, we have to state that the pieces of the jigsaw puzzle on the table about flood risk understanding, the approach for reconstruction, risk reduction measures and integration of a long-term sustainability approach differ greatly from the desired picture everyone wants to paint, and we find that the road towards the desired target picture is still long; unless society significantly increases the intensity as well as the speed of measures. Unfortunately, we have already heard that for many it is inconceivable that such an event would ever occur again. Would society respond better to the forecast of a disaster next time, would they listen to first responders who hopefully are indeed preparing for disaster scenarios worse than what is listed in current manuals? We don't know.

As a society, we urgently need to consider which measures, especially in the run-up to such major events, we want to undertake and implement. The large number of deaths and the extent of the disaster area stretching over dozens of kilometers must serve as clear evidence that the threat situation in Central Europe due to natural hazards has changed or at least intensified again. Events from the past, e.g. 1804 and 1910 but also 2016 in the Ahr Valley and in 1993 in the Ardennes and 1995 along the Meuse in Belgium, have been forgotten or dismissed to such an extent that they have had insufficient influence on today's decisions. We hope that our findings and recommendations will help to ensure that intense natural events can be planned more often in the future and then be better managed. We also believe that while our analysis by nature is focused on where the effects were most devastating – Germany – that many of the lessons apply to other countries. Collaboration across the region is already strong, and for example Luxembourg is using technical guidelines and expertise from Germany, and the Netherlands could have seen much more damage had the event taken place in their smaller rivers, as opposed to the rivers in Germany. As such we are confident our findings are scalable and valid across Europe.



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Executive Summary

Introduction

From July 12-July 19 2021, low-pressure system "Bernd" brought heavy rainfall with widespread rainfall totals of 100 – 150 mm to Western Europe, leading to severe flooding in several Western German states, particularly along the rivers Ahr, Erft, Kyll, Prüm and Inde, and in Belgium (particularly in Wallonia), Luxembourg and the Netherlands along the Meuse River and its tributaries, particularly the rivers Vesdre, Ourthe and Hoëgne. Further affected were the German states of Saxony and Bavaria; and Austria, France, Italy, Romania, Switzerland and the United Kingdom. Rainfall records at many measurement stations were broken, although no new absolute country records were set, with the exception of Luxemburg, where the 12- and 24-hour-records for the month of July were broken. The same can be said for the floods, surpassing gauge record highs especially along the Ahr, where estimated water levels were multiples of the prior measurement record (3.71 m at Altenahr gauge). Across the continent, over 230 people died in the floods. Germany suffered the highest death toll with about 190 casualties (134 in the Ahr valley alone), followed by Belgium with 42 casualties (23 in the village of Pepinster alone). Preliminary estimates of the total economic losses in the affected areas across Europe range from EUR 40-50 billion. For the insurance industry, this event was reported as the largest industry loss for 2021, with estimates of insured losses reported by the market in the EUR 10-13 billion range across Europe and ca. EUR 8.2 billion for Germany. This makes the 2021 floods the costliest disaster in Germany and the deadliest in roughly sixty years, above the losses from the major river floods in 2002 and 2013 and from storm "Kyrill" in 2007. Flood expert A. Thieken points out an interesting consequence of that: Germany is likely to miss the first target of the Sendai Framework for Disaster Risk Reduction, the reduction of the death rate due to natural hazards.

Similarly, as one tries to put the 2021 floods into perspective and compare with prior events, terms like "never seen before" or "unimaginable" were used. Though clearly for almost everyone impacted it was an unimaginable event, it was only so because we have chosen to forget or discount previous floods of this scale. We can no longer afford such selective memory and need to further look back into the past and learn from the historic floods of similar magnitude that have happened, for example in the Ahr valley in 1804 and 1910. When comparing floods and quantifying their likelihood, often terms like the 100-year flood are used, forgetting this is a mathematically calculated, statistical construct, often based on limited data and much shorter than 100 years[1] . The current practice how flood maps are produced and utilized should be reconsidered, and actionable flood risk maps for first responders are required to know where flood water will go and which vulnerable people and infrastructures are located there.

Naturally, this forensic analysis focuses on the areas where improvements can be made. Nevertheless, we try to highlight important elements that have gone well. These include the great solidarity lasting until today, the large number of spontaneous volunteers, the direct and good cooperation between response organizations at the technical level, thanks to good connections and personal contacts, the quite good weather forecasts, the generous provision of financial reconstruction aid and the mostly swift and simplified process for reestablishing critical infrastructure.

The high human and economic costs of the event brought systemic problems within the flood risk management system to light – some of which are not new. Our initial analysis focuses on the challenges of forecasting dynamic summer weather and the failure of early warning systems to result in tangible actions at the local level and within the population, which did not display a strong knowledge about the risks; the challenge of incorporating historic events into both the too-short data record to reflect them in common flood statistics to delineate adequate flood zones and into human imagination to understand what might happen; the breakdown of critical lifeline infrastructure – especially related to telecommunication and road access; coordination challenges in the response phase due to the size of the event not considered in existing disaster scenarios; and the lack of a well-coordinated, comprehensive reconstruction plan that would align with the expectations and timelines of the various actors and would achieve sustainability and reduced flood risk in the future. In particular, we find a deeper understanding of resilience and holistic disaster risk management (DRM) is missing. A shift of awareness and the ability to appropriately act is necessary, particularly as weather extremes become more frequent and intense, leading to severe flooding in areas where the population, especially the most vulnerable, is underprepared and the way of living is inadequately adapted to scenarios such as those experienced in this and in prior, historic floods.

The key insights and recommendations outlined in this report are part of a wider series of post-event reviews, using the Post Event Review Capability (PERC) methodology, that the Zurich Flood Resilience Alliance[2] has been conducting since 2013. The trends are clear – impacts from disasters are getting worse. After a disaster there is rarely the time to learn what happened and what could be done better in the future. However, the recovery period is also a key window of opportunity to take action to reduce future risk. The public PERC methodology[3] helps meet this urgent need. PERCs generate actionable recommendations for reducing future damage right when they are needed most. The aim is to answer questions related to various aspects of flood resilience, including preparedness, catastrophe response, recovery and reconstruction, and risk reduction. It looks at what has worked well, shares best practices, and identifies opportunities where there is room for further improvements. This report follows over 20 other PERC studies and adds to the global

1 Flood probabilities and event occurrences are often indicated as 'return periods' and signify a statistical average based on past events. A '100-year' flood has a one percent chance of occurring in any given year. Yet a home in a 100-year return period flood zone faces greater than 26 percent chance of being affected at least once by a 100-year flood over a period of 30 years, and a chance greater than 64 percent of being affected by such an event over a 100-year period. Therefore, annual probabilities (for example, a '1 percent chance per year') are often a better explanation.

2 https://floodresilience.net/zurich-flood-resilience-alliance/

3 A PERC manual, updated 2020, is publicly available at https://www.zurich.com/en/sustainability/people-and-society/zurich-flood-resilience-alliance/learning-from-post-flood-events

insights gathered from previous big flood events, including patterns of similarities that we also have analyzed and provided in a summary report for a wider, global audience.

The Bernd floods, the severity of which have been linked to climate change, came at a time when climate change was and continues to be at the center of national and international political debates. Not only did the event highlight the urgency to address the climate crisis by drastically reducing greenhouse gas emissions, it also raised the question about limits to and failures of DRM and climate change adaptation. As traditional approaches are demonstrably not enough, how can countries and communities adapt to the new realities of climate change? If more transformational approaches are needed, what could they look like? In this report, we provide both key insights and concrete recommendations drawn from this flood event. Preparing for the future requires that we learn the lessons; and, learn not just for those areas that were affected this time, but in particular areas with similarities to the areas most impacted by Bernd, areas that could suffer similar losses in a future flood. It is especially those areas that must take action now to get to a higher preparedness level. As we have seen in the devastated areas, planning for reconstruction and implementing a forward-looking approach at the same time is nearly impossible as the affected population wants to get back to normal. Hence, often, opportunities are missed to improve and build forward - which needs to change.

Acronyms

ADD	Aufsichts- und Dienstleistungsdirektion Rheinland-Pfalz (Supervisory and Service Directorate for Rheinland-Palatinate, serving as intermediary between the state government and local self-government)
ARD	Arbeitsgemeinschaft der öffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland (Working Group of the public national broadcasting corporations in Germany)
BBK	Bundesamt für Bevölkerungsschutz und Katastrophenhilfe - Federal Office of Civil Protection and Disaster Assistance
CAP	Common Alerting Protocols
CEMS	Copernicus Emergency Management Service
CGDIS	Corps Grand-Ducal Incendie & Secours
CPAS	Belgian regional social services
CRC-W	Regional Crisis Center of Wallonia
DKKV	Deutsches Kommitee Katastrophenvorsorge e.V. (German Committee for Disaster Prevention)
DRK	Deutsches Rotes Kreuz (German Red Cross)
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (German Association for water management, sewage and waste)
DWD	Deutscher Wetterdienst (German National Weather Service)
EFAS	European Flood Awareness System
ERCC	European Commission's Emergency Response Coordination Center
EUSF	European Union Solidarity Fund
EWS	Early Warning System
GDP	Gross Domestic Product
GDV	Gesamtverband der Deutschen Versicherungswirtschaft (German Insurance Association)
GMLZ	Gemeinsames Melde- und Lagezentrum (joint information center of the BBK)
GNI	Gross National Income
GRC	German Red Cross (Deutsches Rotes Kreuz)
ISB	Investitions- und Strukturbank Rheinland Pfalz (Investment and Structural Bank Rheinland-Palatinate
LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (State Office for Nature, Environment and Consumer Protection, NRW)
LAWA	Bund/Länder-Arbeitsgemeinschaft Wasser (Federal-State working group on water)
LFU	Landesamt für Umwelt (Environment Office, Rhineland-Palatinate)
MoWaS	Modulares Warnsystem (Modular warning system)
NINA	Notfall-Informations- und Nachrichten-App (warning app in Germany)
NRW	North Rhine-Westphalia
PERC	Post Event Review Capability
RLP	Rhineland-Palatinate
RMI	Royal Meteorological Institute of Belgium
SGD	Struktur- und Genehmigungsdirektion (Nord) Rheinland-Pfalz (Structure and Approval Directorate, North Rheinland-Palatinate)
SWR	Südwestrundfunk (a regional public broadcasting corporation, serving SW Germany)
THW	Technisches Hilfswerk – Federal Agency for Technical Relief
ÜSG	Überschwemmungsgebiet (flood zone)
WWA	World Weather Attribution project

Section I: Physical Context

Low pressure system "Bernd"

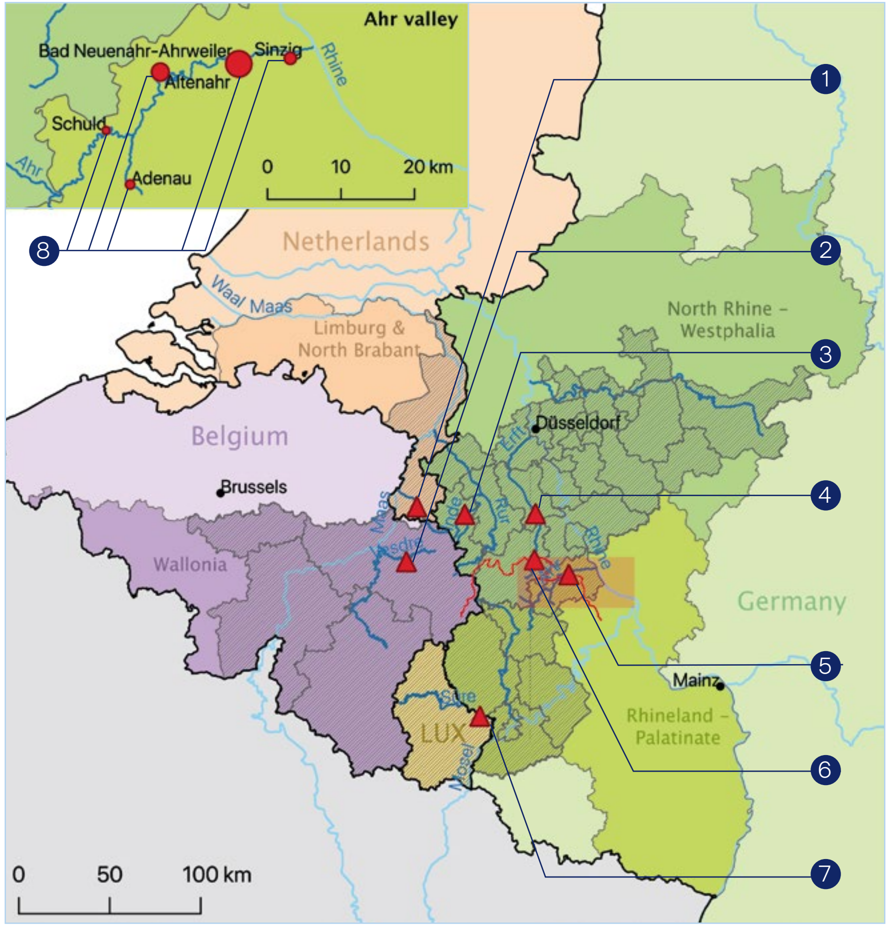
From July 12 to July 19, 2021 a low-pressure system called "Bernd" stalled over Western Europe, causing heavy precipitation throughout the region. Widespread precipitation of 100 – 150 mm fell on already saturated soils, a result of an already wet spring and summer. The result was severe flooding in several Western German states, particularly along the rivers Ahr, Erft, Kyll, Prüm and Inde; and in Belgium, Luxembourg and the Netherlands along the Meuse river and its tributaries. Further affected were Eastern parts of Germany (Saxony and Bavaria), Austria, Italy and Switzerland (EU Copernicus, 2021).

Early indications of potential severe weather became evident a few days ahead of the event. The weekend before the event week, the European Flood Awareness System (EFAS) saw an extreme event building up. It initially identified a high probability of flooding for the Rhine on July 9 and 10 and for the Meuse on July 11. Eventually the potential for serious flooding across a wider region became apparent, but it was difficult to predict which locations exactly might be affected (EFAS, 2021). EFAS, part of the Copernicus Emergency Management Service (CEMS), had been established after the severe 2002 floods in Europe and tries to achieve two things: Earlier flood warning for participating national and regional authorities across Europe and to the European Commission's Emergency Response Coordination Center (ERCC), and to pick up extreme possibilities.

It is typically challenging to generate accurate forecasts during dynamic summer weather conditions. It was difficult to predict which locations might be affected. Particularly, for any one location, including small countries like Luxemburg, it was not clear whether they would be affected at all given the uncertainty about where the rain might fall. This uncertainty was also affecting the national weather services and then the flood forecast procedures and potentially delayed earlier warnings and preventative action. It wasn't until July 11 and 12 that it became clearer to national weather services that "Bernd" would indeed bring damaging amounts of rainfall to specific locations within the Western and Central part of continental Europe. The main event unfolded between July 13 and July 15.

There were three aspects of Bernd that were unusual – the geographic scale, the intensity of rainfall, and the timing, coming in the summer rather than the more typical winter flood season. These are explored, by country, below. The figure and list below provide an overview of all provinces or districts affected by "Bernd". Due to the different severity of the impact between the regions and the extensive damage caused by "Bernd", this report focusses on the heavily impacted districts in the Ahr Valley and as well as the severely affected provinces in Belgium. Many of the results also apply to other affected areas. In cases where we encountered local peculiarities in areas outside the focus regions, we explicitly mention them in the report.

Country	Region	Province/District
Belgium	Wallonia	Liège Luxemburg Namur Walloon Brabant
Germany	North Rhine-Westphalia	Bochum, Kreisfreie Stadt Bonn, Kreisfreie Stadt Düren Düsseldorf, Kreisfreie Stadt Ennepe-Ruhr-Kreis Essen, Kreisfreie Stadt Euskirchen Hagen, Kreisfreie Stadt Heinsberg Hochsauerlandkreis Köln Köln, Kreisfreie Stadt Leverkusen, Kreisfreie Stadt Märkischer Kreis Mettmann Oberbergischer Kreis Oberhausen, Kreisfreie Stadt Olpe Remscheid, Kreisfreie Stadt Rhein-Erft-Kreis Rhein-Kreis Neuss Rhein-Sieg-Kreis Rheinisch-Bergischer Kreis Solingen, Kreisfreie Stadt Städteregion Aachen Unna Wuppertal, Kreisfreie Stadt
Germany	Rhineland-Palatinate	Ahrweiler Bernkastel-Wittlich Eifelkreis Bitburg-Prüm Trier Trier-Saarburg Trier, Kreisfreie Stadt Vulkaneifel
Luxembourg	Luxembourg	Luxembourg
Netherlands	South Netherlands	Limburg



Affected district or province | Flood causing rivers | Eifel mountains

1. Town of Valkenburg
- Flooding caused by river Geul
- 700 homes rendered uninhabitale
- Emergency evacuation of three carez homes

2. Liège province
- Flooding along river Vesdre causing severe damage in the town of Verviers and Pepinster
- City of Liège urged citizens to evacuate
- Several buildings collapsed
- 31 dead

3. Towns of Stolberg & Eschweiler
- Flooding along river Inde and Vicht causing severe damage
- Hospital in Eschweiler flooded, requiring to evacuate 300 patients
- Open pit coal mine “Inden” near Eschweiler flooded, resulting in one fatality

4. Town of Erftstadt
- River Erft leaves river bed flowing through Blessem neighborhood and floods nearby quarry
- Head erosion leads to collapse of several buildings

5. Ahr valley (see inset)
- Fast rising flood in narrow valley
- Severe damage to buildings and infrastructure over 50km strech
- 134 dead

6. Euskirchen district
- Severe flooding along Erft river
- Steinbachtal Dam at risk of collapsing
- 27 dead

7. Sûre (Sauer) river
- Flooding along the river Sûre
- Evacuation of people in Echternach, Rosport and Steinheim

8. Number of deaths
- Adenau (incl. Schuld): 6
- Sinzig: 13
- Altenahr: 33
- Bad Neuenahr-Ahrweiler: 69
- Other: 13

Germany

In Germany, intense rainfall from “Bernd”, a combination of continuous, steady rainfall coupled with intense precipitation that transported moisture continuously to the region, where it was forced to rise due to the topography, during the night of July 13-14, led to catastrophic floods. 135 people died in Rhineland-Palatinate (RLP), (134 in the Ahrweiler district, one in Trier), 49 in North Rhine-Westphalia (NRW), of which 27 in Euskirchen, and two in Bavaria. The ex-post analysis of the German Weather Service (DWD, 2021) indicated rainfall totals of 150 mm in distinct areas, and widespread rainfall of over 125 mm for a duration of 72 hours. On July 13, peak measurements were 241 mm within a 22-hour period at weather station Hagen in NRW in the Ruhr catchment, on July 13. From July 14-15, rainfall was persistent, leading regionally to a total of 150 mm precipitation in less than 24 hours – for comparison, total average monthly rainfall amounts in the area are ~70mm (e.g. CEDIM, 2021, DWD, 2021). A particularly affected area was the Eifel region along the entire river basin of the Ahr river – starting as far upstream as Ahrdorf, then on to Schuld and Altenahr through Bad Neuenahr-Ahrweiler to Sinzig, where the Ahr empties into the Rhine – as well as the Erft and the Rur rivers and the area around the Swist and Olef rivers.

River gauge data is quite scarce for these smaller and mid-size rivers compared to the Rhine and Elbe river, and the gauges where they exist are not primarily designed to support flood predictions for local use; rather, they serve a multitude of purposes including forecasts for the main rivers. In the “Bernd” floods in this area, many of the gauges on the secondary and tertiary river were destroyed or provided unreliable measurements during the event. Additionally, several villages and towns are located upstream of the first gauge station. In the Ahr valley, the water levels started to rise in the morning of July 14 and the peak floods likely happened in the early afternoon (upstream Ahr area near the associated community Adenau and Adenauer creek) and then moved on to reach the middle and lower Ahr valley in the evening and into the night. In Altenahr, the local authorities estimate water levels reached 6-7 m in the evening of July 14, when the gauge stopped working (the prior measurement record at the gauge station had been 3.71 m). It is interesting to note in terms of travel times of the flood wave that the Altenahr gauge stopped working on July 14 at 19:15 and the Bad Bodendorf gauge stopped working only seven hours later on July 15 at 2:15 (LfU, 2021).

Latest estimates from authorities assumed that water levels were 7 m or more in the Altenahr gauge area, and field observations and calibrations estimate the level to be as high as 10 m due to blockage effects especially at some of the lower bridges. What made the situation even more difficult both for the affected population as well as for hydrologists reconstructing the flooding are the descriptions of strongly fluctuating water levels and "flood waves" rushing through, when blockages were broken and suddenly released water and debris that had backed up, both evidenced by the damage patterns in the field and photos and videos.

Experts in historic hydrology have tried to reconstruct the 2021 floods and put them into perspective with the earlier, historic floods of 1804 and 1910 (Roggenkamp and Herget, 2022). They find that the upper Ahr catchment was the driving contributor to the 2021 floods, as several of the small, tributary creeks, especially those towards the North of the valley, brought an amount of water to the Ahr river that it rarely carries itself. It is estimated that at the Müsch gauge the flood was in the order of 500 m3/s, exceeding the prior peak flow (132 m3/s in June 2016) by a factor of four. They further calculated the order of magnitude for the peak flow near Dernau, further downstream, to be between 1000 and 1200 m3/s, comparable with the biggest historic event in 1804 (the highest measured flow at Altenahr was 236 m3/s, recorded in the 2016 floods). Evidently, big floods like the 2021 flood in the Ahr valley have happened in the past, with the 1804 flood even reaching a slightly higher water flow even with less densely populated valley floors and fewer overpaved surfaces than today.

The decisive measure for the delineation of the statistical "100-year flood" at Altenahr is 241 m3/s. DWD calculated the quantity of rain in some areas of Germany to have return periods of 100 years or less frequent. The World Weather Attribution (2021) report estimates the July 2021 Ahr river flood to be rarer than 1:500 per year based on preliminary data from available flood statistics. CEDIM (2021) has looked at the statistical calculation of extreme floods in Baden-Wurttemberg state and outlines that using load factors the flood observed at Altenahr could be estimated as being HQ10'000 or beyond. This issue with flood statistics and results yielding extremely long return periods is discussed later in the report.

Belgium

In Belgium, "Bernd" stalled from July 13-16, leading to maximum precipitation of 291 mm in 72 hours measured in Jalhay, 230 mm in Spa, 213mm in Mont-Rigi, and 209 mm in Ternell. Most of this rainfall occurred July 14-15. The data for rain gauges like Jalhay were so extreme that meteorologists initially assumed the measurements were faulty. Depending on the method, the estimated probabilities for this amount of rainfall range between 1:100 to 1:1000 per year. However, only limited time series data from the above weather stations is available and uncertainty for the estimated probabilities is high. The intense rainfall caused flash flooding through the basin, resulting in 42 deaths and severe damage to infrastructure. Belgian Minister of Home Affairs Annelies Verlinden described the event as "One of the greatest disasters our country has ever known."

Between July 13-19, 2021, the high flows of the Vesdre and its tributaries caused the destruction of most measurement stations downstream of the Eupen and Gileppe dams. The flood peak could only be recorded on the Magne à Forêt, with a value of 43.4 m³/s on July 14. The Pepinster sur l'Hoëgne station also recorded part of the flood, with a maximum flow of 390 m³/s on July 14. The contribution of the Hoëgne river to the flow of the Vesdre, at its outlet at Pepinster, was estimated to have been between 200 and 400 m³/s. None of the gauges midstream of the Vesdre recorded reliable data, but based on the flood water marks discharge for the Vesdre is estimated to have been between 420 and 57 5m³/s. Similarly, estimates based on water marks further downstream show values of 535 m³/s in Trooz and 600 m³/s in Chaudfontaine. For the river Ourthe, the maximum discharge at Sauheid was around 1150 m³/s and at Angleur around 1429 m³/s. For the river Amblève, the discharge at Martinrive was 661 m³/s.

For the Vesdre, the recorded and estimated flows exceeded the range of measurements usually encountered at the stations by far. For the upstream part of the Vesdre at Verviers a probability of 1:200 per year was estimated. For downstream parts this could even be higher. For the Ourthe and Amblève the estimated probabilities are 1:25 to 1:50 per year in the upstream parts and up to 1:100 per year in the downstream parts.

Luxembourg and the Netherlands

In Luxembourg, "Bernd" resulted in over 12 hours of continuous rainfall. Two weather stations recorded new 24-hour maxima, Findel with 79 mm and Godbringen with 106 mm. The subsequent flooding affected the entire country, starting with surface flooding and flooding in small rivers, then moving to the larger river systems. At many river gauge stations in Luxembourg, the 1:100 per year flood level was exceeded, with absolute records measured at 15 stations. Prior records were set in winter, highlighting the unusual nature of "Bernd" that caused a summer flood.

In the Netherlands, the observed Meuse two-day rainfall and peak discharge was estimated to have a probability of 1:100 to 1:1000 per year. Precipitation forecasts days in advance indicated a high chance of excessive rainfall in the area; nonetheless, even as events began unfolding, the forecasts for peak discharge were being increased. For the recorded water levels, probability is assessed at roughly 1:200 per year for the Meuse at Borgharen and decreases to 1:15 per year further downstream. In the tributaries in Limburg the probabilities of occurrence of the recorded water levels vary widely. At many locations along the rivers Geul, Geleenbeek and Roer, probabilities are estimated to be between 1:100 and 1:1000 per year.

Physical landscape

The areas most affected by the 2021 floods are along tributaries in the Rhine and Meuse catchments. Particularly along the Erft and Inde in North Rhine-Westphalia (Germany), the Ahr in Rhineland-Palatinate (Germany), Vesdre in Wallonia (Belgium), the Sauer in Luxembourg and the Geul in Limburg (Netherlands). This is an area of complex and variable terrain. The significant spatial variability of rainfall intensity led, in some cases, to very different responses in neighboring locations. While the heavy rainfall has led to significant water levels and severe flooding in smaller tributaries, the Rhine and Meuse rivers themselves did not see significant flood levels reached.

Geology and Geography

The headwaters of the severely affected Erft, Inde, Ahr and Vesdre rivers are in the mountainous regions of the Eifel and High Fens as well as the hilly Ardennes. The Eifel is a middle mountain region characterized by its river valleys. Its southern part is located in RLP and a smaller, northern part is located in NRW. This complex topography with, in parts, very steep and narrow valleys, lead to a channeling of the rainfall falling over the area with small creeks and streams directly contributing to the discharge of the rivers. Together with the slate bedrock of the Rhenish Massif, which is largely impervious to water and saturated soils, heavy rainfall directly contributes to discharge leading to fast rising flash flood type events – the term "flashy rivers" has been coined. Because the valleys are so steep, there are almost no retention areas, so heavy rainfall leads to quickly rising, high water levels.

The lower and middle reaches of the Erft, Ahr, Inde and Vesdre are characterized by a widening of the valley floor, which allows excess water to spread out but also contributes to more widespread flooding. Due to the wide and flat topography of the flood plain, these areas have larger urban settlements such as Bad Neuenahr-Ahrweiler and Sinzig on the Ahr, Euskirchen on the Erft, and Verviers on the Vesdre. Settlements at the confluence of two rivers, such as Sinzig at the mouth of the Rhine or Pepinster at the confluence of the Vesdre and Hoëgne, are additionally affected by backwater effects and compounding flood waves.

Urbanization and sealed surfaces

The long settlement history in the flood affected areas has led to several hydro-dynamically relevant anthropogenic changes in the landscape. On a general level, not exclusive to the affected areas, is the reduction of natural water retention capacity from vegetation and soils due to land-use changes including deforestation, increase in impervious surfaces through urban expansion and compacted soils from heavy machine use in modern intensified agriculture including viniculture in the heavily affected Ahr valley. Apart from these more general effects and the settlement in former flood plains after narrowing and straightening of riverbeds especially in the 1900 but still ongoing in the 2000s, there are a several area-specific changes to the physical landscape which directly influence the flood regime in the affected regions. In urban areas, the large share of sealed surfaces directly leads to surface water flooding when the intensity of heavy rainfall exceeds the capacities of urban drainage systems. Urban expansion has increased the area covered by sealed surfaces; this can directly lead to surface water flooding when the intensity of heavy rainfall exceeds the capacities of urban drainage systems. The densely populated area in the Ruhr valley in NRW is particularly prone to this type of flooding, further exacerbating flooding coming from smaller rivers and streams.

The expansion of transport infrastructure especially in narrow valleys such as the Ahr valley plays a key role in the flood characteristic with over 60 main road and railroad bridges that act like dams after log jams leading to higher water levels upstream and additional flood waves once they break. Together with increased settlement activities, the riverbed has been further narrowed and channeled, leading to higher water levels and flow velocities further exacerbating flood impacts.

Another flood relevant anthropogenic change of the physical landscape is the erection of dams in the early 20th century to improve the water supply for both industry and the local population, which can exacerbate flood events when not managed carefully or when the design levels are exceeded. Lake Eupen damming the head waters of the Vesdre river had to release 193 m3/s during the peak of the flood to prevent the dam from breaking, contributing to a third of the maximum discharge that led to severe flooding in the downstream communities of Verviers, Pepinster, and Liège[4] . Similarly, the Steinbach dam in the head waters of the Erft river was overtopped during the 2021 flood events and at risk of breaking, causing the evacuation of 15'000 residents in downstream towns and villages (NRW, 2021). And in the Rur valley, a dam overflowed and a levee near Ophoven broke, leading to widespread flooding in downstream communities.

The last flood influencing anthropogenic factor in the affected areas are opencast mines. Two mines in NRW were flooded after previously redirected rivers left their channeled riverbeds. In 2005, the Inde river was rerouted from its original, natural bed around the pit due to progressing work. In the 2021 floods, along the Inde river a levee was overtopped and the Inde went back to its old natural course, causing the still operating lignite quarry Inden to flood. Along the Erft river a quarry was flooded destroying several buildings in the nearby village of Blessem (part of the city of Erftstadt) after retrogressive erosion caused them to collapse. Further damage hindering logistics was also caused on several state highways and the national routes A1 and A61 as foundations were undercut.

4 Data published by the mobility and infrastructure ministry SPW in Belgium. An independent assessment requested by the Walloon government looking at the Vesdre river dam management indicates it was not management decision that led to high outflows, but they were necessary to avoid damage from the dam (https://www.grenzecho.net/60193/artikel/2021-08-08/ministerium-prazisiert-information-bezuglich-der-wesertalsperre-eupen).

While none of the mentioned characteristics and anthropogenic changes in the landscape has individually led to the catastrophic flood events, the combination and interplay between several factors led to water levels that exceeded in many areas those estimated by hydrodynamic models. For this type of extreme event, the decisive factor were the total amounts of rainfall, exceeding the infiltration capacity of the soils.

Historic Flooding in this region

Small, localized floods are not atypical in Western Europe; all of the areas impacted by "Bernd" are familiar with flooding. Events on the scale of "Bernd", both in terms of the geographic extent and the precipitation intensity, are of course rarer, but not unprecedented. Big, devastating, floods with high fatality rates and extreme damage have, except for Luxemburg, occurred before. What was uncommon about the floods from "Bernd" compared to recent decades was the size, timing – in summer rather than the more typical winter flood season, especially for Luxembourg and the Netherlands – and that the level of development and habitation in the impacted areas has increased dramatically since prior historic events, resulting in hydraulic changes that exacerbated flood impacts.

Germany

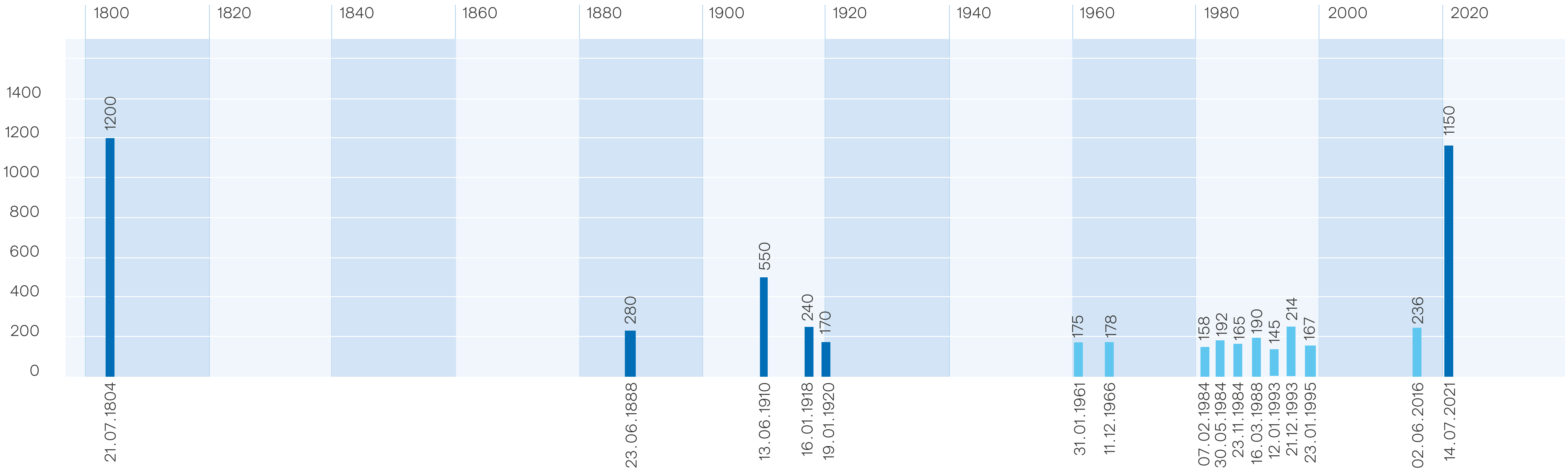
In recent decades, Germany experienced two major river floods in 2002 and 2013, affecting the big rivers, especially the Danube and the Elbe. A series of local flash flood events took place in 2016, for which we published a PERC report. Prior to that, the states of RLP and NRW had seen two big Rhine river floods in rapid succession in 1993 and 1995 (BAFG, 2022). The damage from "Bernd" exceeded the damage of these prior events. However, events of the scale of "Bernd" were not exceptional locally.

In particular, the Ahr valley experienced big, historic floods in 1601, 1804, and 1910. The latter two were summer floods in July and June, respectively. Thieken et al. (2021) point out an interesting pattern when reviewing the flood statistics: Only 14 out of the 74 annual flow maxima are in the summer month of April through October, the rest is in the winter months. However, all big flood events, including 1804, 1910, 2016 and now 2021 occurred during the summer months. It therefore seems to be a different flooding regime, which will be discussed more in detail later. The 1910 flooding killed up to 52 people in the Ahr valley, 1804 there were 63 fatalities (Janta and Poppelreuter, 2010). It was reported that almost every bridge in the valley was destroyed by the 1910 flooding. The Ahr valley railway was under construction at that time. Many of the fatalities were construction workers, and the bridges played a major role as timber meant for the construction turned into flood-carried debris and blocked the bridges. The 1804 flood was likely even more severe. Roggenkamp and Herget (2014, 2022) have reconstructed the historic flood events of 1804 and 1910. They liken the 2021 event to the 1804 event and underline that while extreme and seldom, the 2021 event was by no means "unique" or "unimaginable". When they introduced their approach for historic flood evaluation in 2014, they concluded:

Yet, this history of floods did not lead to action. Far-reaching flood protection plans, developed in the 1920s following the Ahr flood in 1910, were never realized. According to records in the state archive, the need for flood protection was crowded out by different interests and more urgent priorities, in particular, the Nürburgring racetrack was built (Büchs et al., 2003). Bad Neuenahr-Ahrweiler's population has more than doubled since the early 1900s to nearly 30,000, and the Ahr has been pushed into a narrower and narrower corridor. This is not easily undone and contributed to creating the risk landscape in which the "Bernd" floods unfolded. A decisive event took place in the Ahr valley in 2016, which showed that the historic memory of these old, past floods was lost. The Ahr valley flood experienced in 2016 – which were widely characterized as a 1 in 100-year event – appear to have, until "Bernd", replaced these earlier floods as the benchmark for an extreme flood. Because the 2016 floods did not cause major damage or result in deaths; many residents and local authorities seemed to perceive that flood risk was manageable and well under control. Thus, despite comparable or larger floods on record, the "Bernd" flooding was unanticipated.

> The results show that the flood from 1804 was the largest flood event on the River Ahr in historic times. The particularly high runoff values of the flood events of 1804 and 1910 are confirmed by written reports. (…) A future challenge is to investigate the likely modern level of an event such as 1804 or 1910 in the settled areas along the River Ahr. Urban expansions reduced retention areas and the peak levels of historic flood events would, most likely, be higher with the current structure.
>
> **Roggenkamp and Herget,**
> 2014

Ahr valley floods
in m3/s, 1804 – 2021



Reconstructed flow   instrumental flow   Source: Flood history infographic. Data based on Roggenkamp & Herget.

In NRW, the heavy rainfall events from "Bernd" have led to severe flooding in the Rhine tributaries of Ruhr, Wupper, Erft, Lippe, Sieg and Swist as well as the Meuse tributaries Inde, Vicht and Rur. The most severe damage was caused by flooding along the river Erft and Swist as well as Inde and Vicht.

Records of flood events in the Erft catchments date back to the14th century. The construction of several flood retention basins in the Erft catchment following severe flood events in the 1950s and 1960s have prevented a number of flood events since their completion. Yet here too, the scale of potential flooding appears to have been underestimated; during the 2021 flood event the design standards of the largest basin "Eicherscheid" were exceeded by a factor of three forcing a release of the water to avoid an overflow and potential collapse (Erftverband, 2021). Several flood events in the towns of Stolberg and Eschweiler along the Vicht and Inde rivers have been recorded. Severe flooding of the river Inde in 1906 caused a collapse of the local wire factory. The last significant flood event occurred in December 1966 along Vicht and Inde and causing damage totalling 3 million Deutsche Mark (EUR 6 million in today's values) in the towns of Eschweiler and Stolberg.

Belgium

Both the Walloon region in southern Belgium and Flanders in the North regularly experience flooding of different scales. In the Walloon region, flooding – especially along rivers in the narrow valleys of the Ardennes – is not unusual during the winter months. Riverbanks are densely populated and extensively exploited for tourism. Some of the examples of historic floods include the 1984 winter floods that were caused by a combination of heavy rains in the Ardennes and snowmelt, and affected much of Belgium. The Meuse winter floods of 1993/1994 and 1995 etched themselves into the historic memory as they were among the most catastrophic to strike the Ardennes and occurred in two consecutive winters. In 2003, following repeated flooding, the Walloon Government thus decided to put in place the P.LU.I.E.S. plan[5] for flood risk management in the region.

Similarly, the Flemish region has experienced regular river and coastal flooding, including storm surges. Examples are the storms of 1953 and 1976 which caused significant flood damage on the Belgian coast and along the Scheldt river and increased public awareness for coastal flood risk and initiated the so-called Sigma plan for a "flood control approach" in the early 1980s (and has since shifted towards a risk-based approach that focuses on enabling a protection against flood damage) for Flanders. However, flood events in Walloon and Flanders tend to differ substantially, as much of the Walloon region is nestled in valleys along riverbeds, with limited space for flood waters, while Flanders is mainly flat with a small section of coast on the North Sea, where it also experiences coastal flooding. As a result, Wallonia is more exposed to consequences from fluvial and pluvial flooding and from mudslides that may follow periods of heavy precipitation, whereas Flanders is more exposed to sewers overflowing following heavy rain.

In recent decades, flooding has become more frequent and severe in Belgium. Examples include the floods in winter 2010/2011, when heavy rainfall caused rivers to overflow in many places across the country, particularly along the Senne and its tributaries and the Brussels-Charleroi canal. The summer 2021 fluvial floods along part of the Meuse catchment and its tributaries however broke the historic records of previous floods, both in terms of historically observed rainfall records and by damage caused. An increase in construction alongside rivers and in other flood prone areas, and an increase in impermeable surfaces in developed areas have been increasing the severity of flooding experienced in recent years. Variations in precipitation and increased occurrence of heavy rainfall are exacerbating this trend. Climate change is expected to further influence peak discharge, with estimates suggesting a clear increase in extreme discharges and variability (5-10%) this century for the river Meuse, for example (Detrembleur et al., 2015).

Luxembourg and the Netherlands

Luxembourg has historically experienced numerous floods in the winter. This includes flooding in 1983 on the Moselle and in 1993, 1995, 2003 and 2011 in the Sauer basin. Floods are a frequent occurrence in the country, and the extent of the damage caused is growing. However, summer floods are a new threat. Intense precipitation led to flash flooding in multiple areas of Luxemburg in June 2018, in particular in the Northeast (Müllerthal), North (Our) as well as, several days later, in the West (Attert) and East (Greiveldange). In May-June 2016 heavy rain led to floods in the South of Luxembourg, and in July 2016 in the north-east of the country. The 2016 floods caused significant material damage and it was an "expensive year for insurance following floods". The climate is clearly changing and exacerbating flood risk in Luxembourg with high likelihood. Geographic rainfall patterns are shifting in winter, increase the frequency of floods. And, despite historical vulnerability to winter floods, the 2016 and 2021 extreme flooding events suggest that summer flooding is a new and growing risk.

The Netherlands, in contrast to Germany, Belgium and Luxembourg, does not only experience floods, they are a global leader in flood control and living with water. Approximately two thirds of the country is vulnerable to flooding, and the country is densely populated. Natural and constructed water management structures are used throughout the country to manage risk. Measures included the widening and deepening of river channels as part of the government's "Room for the River" policy, a high level of protection for dams, dikes and levees, and evacuation schemes to make sure that people can be moved to safe places. Furthermore, every major flood event is used as an opportunity to learn and improve systems, policies, community and individual awareness and engagement. Consequently, though the Meuse River reached record high water levels, the level of destruction in the Netherlands was not the same as seen elsewhere; however, the Netherlands did receive less of the intense rainfall and flash flooding seen in other countries in the 2021 event.

5 http://environnement.wallonie.be/de/dcenn/plan_pluies/).

Future flooding trends

Climate change is making extreme rainfall events more common. As a consequence, we should anticipate that events like "Bernd" – both the geographic scale and rainfall intensity – will become less rare. The World Weather Attribution project (WWA, 2021) has assessed that weather patterns like "Bernd" are more likely due to climate change. The physical explanation for this is because a hotter atmosphere can hold more water; an increase of 1 degree Celsius in temperature increases the capacity of air to hold moisture by 7%. Higher air and ocean temperatures also lead to more rapid evaporation, which in turn leads to more extreme precipitation events and heavier storms. Germany's National Meteorological Service (DWD) said that heavy rainfall events have gotten stronger as temperatures have risen. It was noted that the rise was strongest during winter and "the picture is still unclear for the summer months" when heavy storms usually strike, since extreme precipitation depends on extreme thunderstorms (Junghänel et al., 2021). The WWA study analyzing the 2021 cut-off low-pressure system "Bernd" adds to this that climate change has increased the intensity of the maximum 1-day and 2-day rainfall event in the summer season in a large-scale region like Europe by about 3 - 19% compared to a 1.2 °C cooler global climate. The likelihood of such an event to occur today compared to a 1.2 °C cooler climate has increased by a factor between 1.2 and 9 for the 1-day event in the large region. The increase is again similar for the 2-day event. How we deal with regime shifts in meteorological and hydrological contexts also has an influence on flood statistics as the assumption of stationarity in the underlying physical processes is violated, which we will discuss more in the corresponding section later.

The warming of the atmosphere is also shifting circulation patterns. The result is more variability than we have seen historically, and increased 'stalling' of storms, allowing them to deposit much greater rainfall volume localy than we expect. There is evidence this 'stalling' is due to a reduced temperature differential between the poles and tropics which results in slower atmospheric circulation. Evidence of climate change stalling of large hurricanes and cyclones has already been documented (e.g. Hurricane Harvey, Houston, USA, 2017; Hurricane Florence, North Carolina, USA, 2018; Hurricane Dorian, Bahamas, 2019). The same mechanisms are likely to lead to a slowing of large storm systems in Europe, and an associated increase in heavy rainfall events and flash floods. Climate scientists in the UK have suggested that slow-moving storms might happen 14 times more frequently across the European continent by the end of the century (Kahraman et al., 2021). There are some indications of an intensification of local extreme rainfall events and subsequent flooding in the summer months as a result of climate change, but due to challenges with climate models representing local rainfall extremes a regime shift from winter to summer flooding has not yet been confirmed.

Section II: Disaster Risk Management Landscape

Socio-economic landscape

The main impacts of Bernd were felt in the federal states Rhineland-Palatinate (RLP) and North Rhine-Westphalia (NRW) in Germany, the province of Liège in Belgium, Luxemburg and the province of Limburg in the Netherlands. Bernd thus affected a relatively large area exhibiting a diverse socioeconomic landscape. The following does not provide a comprehensive socioeconomic assessment but spotlights key aspects that were relevant in relation to the floods.

The flood affected areas in Germany exhibit some distinct features along different dimensions of socio-economic vulnerability. Most of the affected districts, both in RLP and NRW, are in the lower third of districts in Western Germany in terms of GDP per capita. The particularly badly affected district (Landkreis) of Ahrweiler had a GDP per capita of EUR 27'426 in 2019, which is much lower than the German average of EUR 41'508.

This was also the case in Belgium; Bernd's impacts in Belgium were greatest in the province of Liège in Wallonia, and in particular in the district of Verviers at the Eastern end of the industrial Sambre-et-Meuse backbone. Since the decline of industrialization following World War II, this area in the valleys of the rivers Haine, Sambre, Meuse and Vesdre has suffered from high unemployment. In 2019, GDP per capita in the district of Verviers was EUR 27'401, which thus ranks in the lower third of districts in Belgium in terms of GDP per capita, versus the Belgian national average GDP per capita of EUR 41'546. This economic stress is mirrored in unemployment rates. In 2019, the district of Verviers had an unemployment rate among the 15- to 64-year-old population of 11.2 percent. The community of Verviers, which was one of the worst hit by the floods, had an unemployment rate of almost twice as much, 21.8 percent.

The socioeconomic situation in the impacted areas of Luxembourg is quite different; while affected areas in Germany and Belgium were relatively poor compared to their national averages, Luxemburg is one of the richest countries in the world. In 2021, average GDP per capita in Luxemburg was EUR 114'370. Similarly, the population of Luxemburg is younger than the one of the most affected areas in Belgium and Germany with an average age of 39.7 years.

Lower income is often correlated with higher vulnerability because people with fewer financial resources may also be less mobile, may have fewer resources to support evacuating or taking preparedness actions, and will have fewer resources to devote to recovery. Lower income also often correlates with less political influence, which can in turn mean less investment in preparedness and risk reduction, weaker services, and lower capacity in local government and civil protection. Age can be a vulnerability factor as older people tend to be physically weaker and thus less mobile, which affects their ability to evacuate and move to higher ground. Age can also be an issue when it comes to technology; the elderly are often less tech savvy and thus may have access to fewer sources of information such as Apps in use for Early Warning.

The flood impacted areas in Germany appear to have also disproportionately affected older people. The population of Ahrweiler is older (46.7 years old) than the German population on average (44.6 years old). In particular, the district's capital Bad Neuenahr-Ahrweiler, where 69 people died, has an average age of 49.7, which is the oldest average population in RLP. Of the 134 people who lost their lives in Ahrweiler district, 106 were above the age of 60. The district of Verviers, the most impacted area in Belgium, is at 41.9 years old not disproportionately older than the national average in contrast to Bad Neuenahr-Ahrweiler. However, within Pepinster and Verviers, many older people lived in the areas close to the rivers and were therefore particularly badly affected.

The floods affected both rural and urban areas, each having distinct features of vulnerability and resilience. In urban areas, access to basic services in the days and weeks after a disaster can often be better than in rural areas. Urban areas typically have stronger, more robust, more redundant critical services and more capacity to quickly reinstate services if they are impacted. It is not unusual for only portions of an urban area to be impacted, particularly by flooding, leaving other areas unharmed. In particular, at least a sub-set of medical services and supermarkets are likely to continue operating, providing a source of food and critical care. The transportation network is denser and political capital is typically higher, meaning disaster relief reaches urban areas earlier. In rural areas, access to services is more difficult and is often only available through one pipe, line, or connection. Fixing that pipe, line or connection may be slow and difficult if it fails. There may be only one medical service, and it may be located some distance from the village. And, there may only be two or three ways in or out of town and those may be easily damaged, relying on bridges or easily blocked or eroded, narrow, mountain roads. Yet, at the same time, social capital and mutual support is often higher in more tightly-knit rural communities. People know each other, and are more likely to know who is vulnerable, where they live, and what kind of support they may need. Corresponding witness accounts were given to us for the respective urban (Bad Neuenahr-Ahrweiler) and rural (Altenahr) communities.

A particularly interesting dimension of socio-economic vulnerability in the Ahr valley is the important role of viticulture and related tourism for the local economy, including mobile or more long-term camping on many campsites in a lovely setting along the Ahr river, and hiking or cycling combined with wine tasting. These economic sectors were heavily impacted by COVID prior to the 2021 floods. There was already little flexibility to absorb further losses or impacts. There is also an ongoing debate about the role of the vineyards on the slopes of the valley and whether they facilitate faster runoff of rainfall into the valley, adding to the impacts of floods. Small but contributing factors are for example how the vineyards are organized and managed, whether the rows of grapes are oriented vertically, down the slope of the typically steep hills, or horizontally with a small counter-slope so that water does not immediately run-off downhill, or adding secondary vegetation to the vineyards (Cerdà & Rodrigo-Comino, 2020).

One of the additional complicating factors in flood preparedness, response and recovery in Belgium is the economic, cultural and linguistic divide between the wealthier, Flemish speaking northern portion of the country and the poorer, French speaking southern part of the country. This divide also became visible in the communications and organizational capacities related to holistic flood risk management, which played a role in the impacts of Bernd in Belgium.

Camping, Cycling and Hiking

The role of campers and campgrounds has gained additional scrutiny after the floods. In the Ahr Valley, there are a number of campsites located along the river. Besides tourists using the campsites, there are also permanent residents living in campers that are no longer mobile and that could therefore not be moved outside of the flood zone quickly.
Some of these permanent campers live there due to the low costs of accommodation and often have their primary residency on these sites.
These campsites deserve a closer look as they played a distinct role in the floods. Not only were they located in highly hazardous areas where the rescue operations were difficult (the only death of a professional first responder took place in such context in the Ahr valley), but they also exhibit particular vulnerabilities that lead to downstream consequences. Campervans that were not removed on time were quickly washed away by the flood and then, together with other debris, blocked the narrow arches of bridges further downstream.
These bridges turned into dams leading to backwater effects and flood waves running down the valley each time one of the bridges broke.

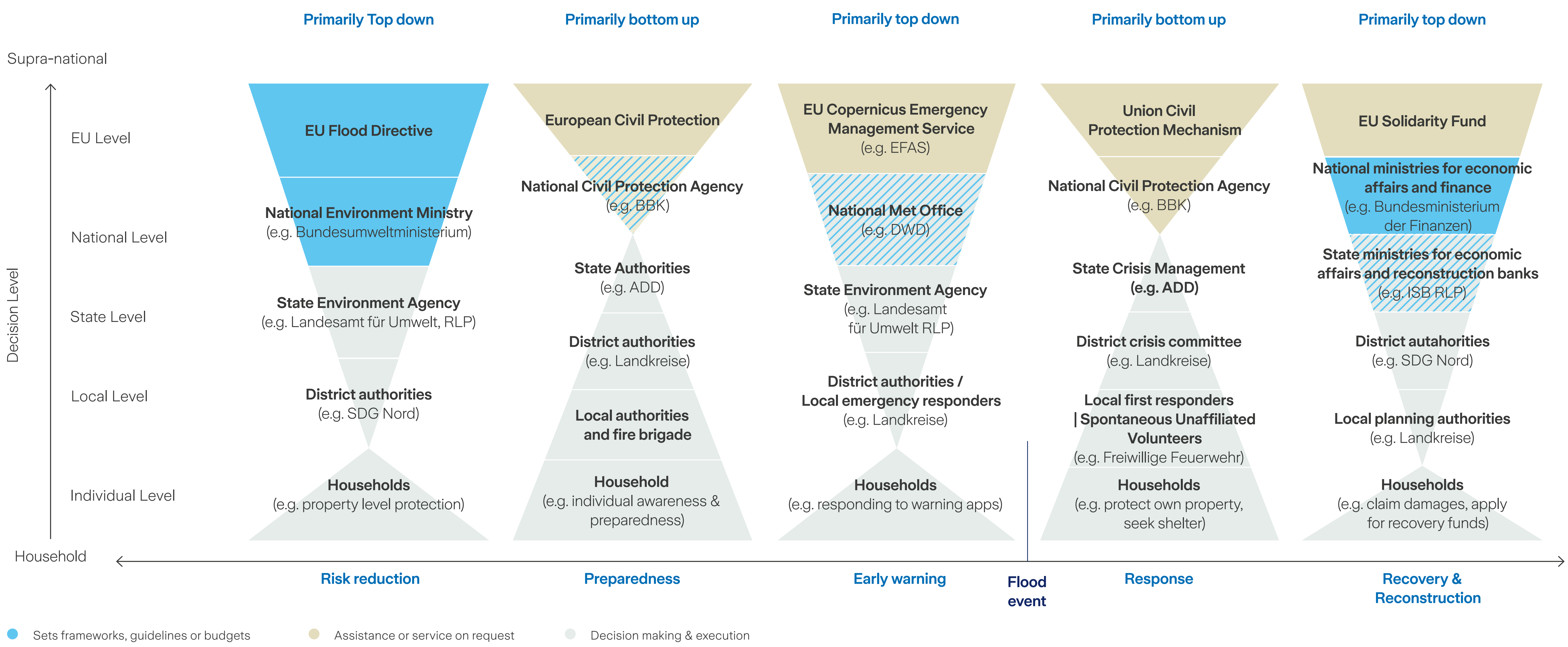
Following the floods, getting clarity on how to redevelop the camping tourism and agree on a planning and execution plan with the higher authorities was found to be very difficult. While the local authorities would rather want to focus on the mobile campers that arrive with caravans, reconstructing campsites that cater for this audience might not be permitted since the minimal infrastructure required was destroyed and as such an exemption from building in the flood zone might not be granted, whereas a heavily damaged but not destroyed more permanent campsite for the immobile, long-term caravaners might be acceptable by law but not make much sense.

Similarly, the well frequented cycle path "Ahrtal-Radweg" cannot easily be reconstructed. Especially in the city of Bad Neuenahr-Ahrweiler with limited space available and the now wider riverbed, it is hard to determine where the path could be rebuilt – even establishing the bike path reconstruction concept might take the rest of 2022. Yet, this is an important asset for summer tourism and often heavily used by children on their way to school so should be wrapped into the overarching Ahr valley reconstruction concept.

Hiking has been the easiest tourism segment to restore. Most of the hiking trails in the hills were unaffected and accessible despite the chaos in the valley. Hikers were urged to return to the red wine tasting trail, since wineries were able to reopen their tasting offers, and lunches can easily be organized as picknicks, so at least there were some tourists - as early as late summer 2021 – providing a little income to the economy and combining this even with donations through the "flood wine" and "SolidAHRity" wine sales.

SolidAhrity – special edition wine for the flood victims, sold in a winery in Dernau. The vineyards are a particularly important economy as well as contributor to the tourism industry in the valley. Michael Szönyi, 5.4.2022

Institutional Landscape



All countries investigated in this PERC report are member states of the European Union and therefore share common frameworks and mechanisms relevant to flood risk management. These include for example the EU Flood Directive, the EU Civil Protection Mechanism, the European Emergency Management Service (of which the European Flood Awareness System) and the EU Solidarity Fund. These frameworks and mechanisms have different degrees of influence on the respective national and subnational frameworks and mechanisms. While the EU Floods Directive as framework legislation defines specific criteria for example on flood risk assessments for EU member states, the EU Solidarity Fund so far only plays a minor role for reconstruction compared to the size of national recovery and reconstruction funds.

Within countries, the responsibility for flood risk management is diffused across levels of authority and a wide range of actors, who are each responsible for different phases of the disaster risk management cycle. In Germany, the responsibility for flood risk reduction is at the level of the individual federal states ("Länder"). The federal states (typically the state's Environment Agencies) are responsible for the flood hazard and risk mapping in accordance with the EU Floods Directive as well as the planning, maintenance, and improvement of flood protection. In the special case of third order streams, which have been primarily affected during Storm "Bernd", the responsibility for maintenance including flood protection infrastructure, lies with the respective local council.

Flood preparedness is structured in a bottom-up manner, where the state structures only step in where individuals and households do not have sufficient capacities themselves. However, our interviewees confirmed that the population has developed an expectation that the state should take on more responsibility and therefore individuals' and households' preparedness levels are low. While minor differences exist between the federal states, in general flood preparedness is managed as locally as possible at the communal and district level, with the fire brigades as the main actor. According to the disaster law of the federal states (e.g. Landesgesetz über den Brandschutz, die allgemeine Hilfe und den Katastrophenschutz; LBKG), it is the responsibility of communities and districts, to establish, train and equip these fire brigades and develop alert and operational plans for the provision of general aid as well as of fire and disaster protection. Federal state level authorities support these efforts and organize relevant capacities that do not exist at the lower levels.

The early warning system is structured in a top-down manner. The DWD provides weather forecasts for the whole country and can issue weather-related warnings. The forecasts are then used in flood models by the respective authorities at the federal state level such as the State Office for Nature, Environment and Consumer Protection (Landesamt für Natur, Umwelt und Verbraucherschutz, LANUV) in NRW. The federal state authorities then share the results of and insights from their models with lower-level authorities, who are usually in charge of issuing warnings and ordering evacuations. Warnings are ordered by the district commissioners (Landrat) or mayors and fed into the modular warning system by the control centers. The digital infrastructure of the modular warning system is provided by the Federal Office for Civil Protection and Disaster Response and complemented by private initiatives (e.g. KATWARN). Warnings can reach the population via different channels such as apps or sirens. Local fire brigades, in some cases supported by the police and aid organizations, support the translation of early warnings into early actions.

The institutional landscape for disaster response mirrors that for disaster preparedness as both are determined by the same law. Disaster response is structured in a bottom-up manner where response should be as local as possible and higher levels such as the district or federal state authorities only step in if the capacities of the lower levels are exceeded or if several communities or districts are affected. When a disaster situation exceeds even the capacities of the federal state, additional support can be requested from other federal states and even other EU countries. The national (e.g. BBK) and EU level structures take a mostly coordinating role.

Finally, recovery and reconstruction is conducted in a top down manner. At the supranational level the European Union Solidarity Fund (EUSF) can provide financial assistance to member states affected by large scale catastrophes where the damage exceeds EUR 3 billion or 0.6% of the GNI of an affected member state. While both Germany and Belgium have applied for money from the EUSF after "Bernd", it is currently not the main financial source for recovery and reconstruction. Unlike the Netherlands, Germany does not have a dedicated disaster response fund and budgets for recovery and reconstruction are decided on an ad-hoc basis by the federal government. With a few exceptions such as federal infrastructure where a small part of the budget is directly spent by the federal government, the largest part of the budget goes to the affected federal states (in this case NRW and RLP). Within the federal states the money is distributed to different responsible bodies and institutions such as the ministry for economic affairs, infrastructure, agriculture and viticulture for reconstruction of state-owned infrastructure or the local councils. Support for affected businesses and private households is processed through the state's development banks such as the Investitions- und Strukturbank Rheinland-Pfalz, ISB. The German Red Cross (GRC) and other aid organizations support the reconstruction by providing support and guidance during the process to apply for insurance or reconstruction fund compensation and contributes with their own financial resources. The district authorities and planning authorities organize the reconstruction including the definition of protection zones where reconstruction is not allowed due to the high risk of flooding.

For all five of these process elements, the people involved from the bottom-up are often the same individuals, departments and organizations. They act continually through all stages of a disaster. Conversely, from the top-down, the actors are often quite different as you move from element to element of the process. This means that each column in the diagram has different actors, expectations, policies and processes working top-down, and the bottom-up actors need to be informed about and working with all of those; if they aren't, gaps in understanding, communication, and coordination can open up. As will be seen in Sections 3, 4 and 5, this is what happened in many elements of the process in different locations during Bernd. The point where the bottom-up and top-down meet, in each one of the five elements shown, is a crucial point influencing whether a hazard event becomes a disaster.

In **Belgium**, effectively several layers of coordination arise from the partition of competences between the Federal State and regions. Responsibilities for flood risk management are thus shared across levels of governance, stretching from the national government in Brussels down to local levels, and the approach to various aspects of the flood risk management cycle differs across the country. Responsibilities for flood risk management are shared across levels of governance, stretching from the national government in Brussels down to local levels, but the approach to various aspects of the flood risk management cycle differs across the country.

In both Flanders and Wallonia, local flood maps form the basis for decision-making, both for emergency management and construction permitting. Flanders maintains a digital portal of flood maps on the waterinfo.be website. The portal includes real-time information about current conditions, as well as 48h flood forecasts. The Wallon government's portal (https://inondations.wallonie.be/) has guidance and past information on floods and flood risk management and hosts the WalOnMap portal with flood maps and the dedicated InfoCrue portal with flood risk data, including information on the current water levels of Wallonia's river systems. However, interviewees noted there are persisting challenges related to the communication of flood maps, including translating the technical information about return periods into actionable information for local decision-makers that struggle to interpret green or unmarked zones as potentially floodable (as was the case during the summer 2021 floods in Wallonia, where most of the areas flooded directly along the Vesdre were located in green or unmarked zones).

In terms of disseminating flood and weather warnings, the divide along the linguistic and organizational boundary between Wallonia and Flanders is also persistent; "Bernd" highlighted a capacity gap in knowledge sharing between the Wallonia and Flanders' hydrological services and the national meteorological service, the Royal Meteorological Institute (RMI) of Belgium. Based on lessons from the 2021 floods, they are now institutionalizing an improved coordination mechanism with the regional services in Wallonia and Flanders, as well as with those in neighboring countries.

In Luxembourg, responsibility for flood risk management lies at the national level. The flood hazard and flood risk maps serve as an information tool for the public on one hand, and also form the basis for risk assessment and the derivation of specific measures on the other. Furthermore, the maps must be taken into account in building permits within defined flood zones in order to ensure flood-adapted construction. The flood hazard and flood risk maps can be consulted on the national geoportal https://maps.geoportail.lu/ under the topic Water – Flood Risk Management Directive. Heavy rain hazard maps for the whole of Luxembourg can also be found there. Current flood reports are published on the flood information page https://www.inondations.lu/, where flood situation reports are also provided. In addition, the measured water levels for 38 gauges are updated every 15 minutes and water level forecasts are published up to 24 hours for 10 gauges. The offer is supplemented by further information on flood forecasts and recommendations for behavior in the event of a flood. The flood reports from the reporting center are also published on the website and app of the national weather service in addition to the flood website inondations.lu. Further developments are already in progress in this area, including Luxembourg's participation in the LHP (Cross-Country Flood Portal) My Level App and region-related warnings.

Section III: What Happened in Germany

Overview

Of the countries impacted by "Bernd", Germany suffered the highest death toll, with ca. 190 casualties (134 in the Ahr valley alone). In RLP, seven districts (Kreise) were affected – Ahrweiler, Bernkastel-Wittlich, Cochem-Zell, Eifelkreis Bitburg-Prüm, Mayen-Koblenz, Trier-Saarburg and Vulkaneifelkreis, and the Ehrang location of Trier city, affecting 65'000 people. In the Ahr valley 42'000 people were affected, of which 17'000 lost property and belongings. 9000 buildings were damaged, including critical infrastructure and public services such as hospitals, schools, and nursing homes. In the Ahr valley alone, 103 bridges were damaged or destroyed. This led to the biggest and longest response and recovery operation by rescue, aid, fire brigade, civil protection and military forces in German history. In the first six weeks following the event, over 20'000 forces were working in the Ahr valley, alongside, uncounted, several thousand private volunteers lending helping hands (and equipment) in the Ahr valley (Wiederaufbaubericht RLP).

In NRW, approximately 20'000 private households and 7'000 commercial properties were impacted across a large region, including: Bochum, Bonn, Düren, Düsseldorf, Ennepe-Ruhr-Kreis, Essen, Euskirchen, Euskirchen district, Hagen, Heinsberg, Hochsauerlandkreis, Köln, Leverkusen, Märkischer Kreis, Mettmann, Mönchengladbach, Mülheim an der Ruhr, Oberbergischer Kreis, Oberhausen, Olpe, Remscheid, Rhein-Erft-Kreis, Rhein-Kreis Neuss, Rhein-Sieg-Kreis, Rheinisch-Bergischer Kreis, Soest, Solingen, Siegen-Wittgenstein, Städteregion Aachen, Unna, Viersen and Wuppertal. The estimated total economic damage in NRW amounts to ca. EUR 12.3 billion.

Other affected German states with losses in the several hundred million EUR range are Bavaria and Saxony. Infrastructure damage also was caused extensively to federal inventory such as national roads, rail and waterways of roughly EUR 2 billion, of which German Railway (Deutsche Bahn) estimates its damage to be EUR 1.3 billion (BMI Abschlussbericht).

> "1804 on July 21st was the terrible Ahr flood. A downpour fell all day long, and the water poured out of the ground. The Ahr carried away houses, barns, stables, beams, trees, household appliances, and empty and full wine casks.

Source: Präsentation Hochwasser im Ahrtal – Historische Betrachtung und die Flut 2021 – Dr. Roggenkamp

Hans-Jürgen Vollrath, Ahr-Foto.de. Flooding in Walporzheim. 15. July 2021

Preliminary estimates of the total economic losses for Germany are ca. EUR 35-40 billion. Early estimates indicate that RLP accounts for over half of the losses for Germany, with roughly EUR 20 billion total economic and EUR 5 billion insured losses. This makes "Bernd" not just the most fatal (fast-onset) natural hazard event since the storm flood 1962 in Hamburg, but the costliest disaster from a natural hazard above the losses from the two major river floods in 2002 and 2013 (total economic losses of ca. EUR 12 billion and EUR 11 billion in today's values, respectively) and also costlier than storm "Kyrill" of 2007 (ca. EUR 6 billion). All of these had a much larger footprint than the extent of the flooding from "Bernd", further illustrating the severity of the "Bernd" floods.

Pre-Event Risk Reduction and Preparedness

Over the past few decades, integrated flood risk management, identifying and addressing risk before it becomes a disaster, has replaced managing floods or disasters themselves. In Germany, this shift was triggered by key flood events, such as the Rhine floods of 1993 and 1995, both dubbed "100-year floods". As a consequence of the 2002 Eastern Germany floods, laws for flood risk prevention were put in practice. The current approach taken by the European Union (EU) to flood risk management is captured in its Directive 2007/60/EC ("EU Floods Directive"). Germany put the Directive into practice in 2010 through their revised Federal Water Act, which requires those areas to be declared flood zones where a flood event is to be statistically expected once in 100 years or more frequently ("Überschwemmungsgebiet", ÜSG). Flood hazard maps outline the underlying hydrological assessment of a 1 in 100-year return period flood ("HQ100"), equivalent to 1% annual chance of occurrence. The flood extents that form the basis of the flood zones are calculated using statistics which are based on the instrumental measurement record.

Flood return periods are derived based on a cooperation for technical instructions on flood statistics and flood hazard assessment, available from the "German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry (Bund/Länder-Arbeitsgemeinschaft Wasser", LAWA. The aims of this Working Group are to discuss in detail questions arising in the areas of water management and water legislation, to formulate solutions and to put forward recommendations for their implementation. Documentation on high and low water aspects are regularly published . Further guidance is provided by the German Association for Water, Wastewater and Waste (DWA), the technical-scientific professional association that unites the experts and managers of the water and waste management industry. They have provided technical guidance on how to calculate statistically relevant flood levels (HQ100, HQlow, HQextreme) incorporating historic floods, but we understand in practice there is still a heavy reliance on the instrumental measurement record and the focus on HQ100 alone. The Ahr flood hazard maps that had been in place when the event happened are based on the gauge measurements available since 1947. The historic flood events that date to a period prior of instrumental measurements are not reflected in those hazard maps. Correspondingly, the design 100 year return period flood flow HQ100 was determined at 241 m3/s.

As part of the flood risk prevention law, various actors, their roles and necessary actions were defined. This includes that water management should focus on retaining flood water, ensuring water can flow without causing damage, protecting areas that can be flooded, and helping to reduce or avoid flood damage. It also includes the role of the individual citizen, who is expected to be aware of flood risk and is required to take reasonable self-protection measures and to adapt the use of their property against flood hazards where necessary (Article 5 Section 2 Water Law).

Based on the flood hazard maps and the official delineation of ÜSG in paragraph 78 WHG, new construction and limitations in the use of the land within the ÜSG are regulated. The law stipulates that areas within the ÜSG may not be zoned in for new building purposes, but then lists numerous exceptions which are frequently used (e.g. construction in ÜSG is permitted when it immediately borders existing construction), meaning that new exposure is still added into hazard zones.

The German civil and disaster protection system is meant to step in when the population's coping capacities are exceeded. It differentiates between peace and war times. In war times, the responsibility for civil protection (Zivilschutz) is with the Federal Office for Civil Protection and Disaster Response (BBK). In contrast, the federal states are responsible for disaster protection (Katastrophenschutz) in peace times. The German disaster protection system is thus decentralized with the federal states taking the lead.

Civil protection, where the federal level takes the lead, and disaster protection, where the federal states take the lead, thus form an integrated assistance and support system. This means that civil protection resources of the federal level can be used to support the federal states in their disaster protection efforts and vice versa. However, the BBK is legally not able to act in a disaster situation, it can only support. Besides the BBK, federal-level resources of the Federal Agency for Technical Relief (THW), the Federal Armed Forces and federal civil protection units can be deployed to support the federal states if a disaster situation exceeds their capacities.

The federal states have their own disaster laws that outline the disaster protection actors and responsibilities within each state. There are a number of commonalities. In all states, the fire brigades are the central actor for disaster protection and the responsibility for disaster protection is based on the subsidiarity principle. The latter means that disaster preparedness and response should happen as local as possible. Higher levels such as the district or federal-state level only get involved if the situation exceeds the capacities of the respective lower level or if several communities or districts are affected.

6 https://www.lawa.de/Publikationen-363-Hochwasser-und-Niedrigwasser.html

For example, as outlined in the table below, according to the state-level disaster law of RLP (Landesgesetz über den Brandschutz, die allgemeine Hilfe und den Katastrophenschutz; LBKG), the commune is responsible for fire protection and general aid and for preparing alert and operational plans. These are implemented by the local fire brigades which are often run by volunteers. The community is responsible for training and equipping these brigades. The next higher level is the district (Landkreis) who is responsible for supra-communal fire and disaster protection including the preparation and implementation of alert and operational plans. The district is also responsible for setting up and maintaining facilities, units and equipment for disaster protection including the crisis committee. The roles and responsibilities of the federal state are with the Supervision and Service Administration (ADD) and the Ministry of the Interior and Sports and are mostly focused at advising, supporting and building the capacities of communes and districts. In disaster situations affecting several districts and exceeding the coping and response capacities of the lower-level authorities the federal state authorities can take the lead and establish a crisis committee.

The state-level disaster law in NRW (Gesetz über den Brandschutz, die Hilfeleistung und den Katastrophenschutz; BHKG) distributes these roles across the same levels in a similar manner as in RLP.

Levels of responsibility outlined in the state law on fire protection, general aid and disaster protection in Rhineland-Palatinate

Level		Tasks and responsibilities
Communal	District-free cities	Fire Protection and general aid - Setting up, training and equipping local fire brigade - Alert and operational plans for fire protection and general aid including a concept for warning and informing the population (in coordination with district) - Awareness raising on fire protection and general protective measures - Data collezction and provision on the state of the fire brigades - Trainings and exercises - Mutual support among communes
District	District-free cities	Supra-communal fire protection and general aid - Hold facilities, institutions and equipment for supra-communal fire protection and general aid Disaster protection - Ensure readiness of units, facilities and institutions for disaster protection - Form, prepare, and equip disaster protection committee ('Stab') - Train disaster protection personal including committee - Alert and operational plans including a concept for warning and informing the population (in coordination with communes) - Trainings and exercises for supra-communal hazards District commissioner - Appoint full-time or voluntary fire and disaster protection officer - Appoints lead emergency doctor and organizational director
Federal state - Supervision and service administration - Ministry of the Interior and Sports		Central tasks relating to fire protection, general aid and disaster protection - Alert and operational plans for nuclear facilities - Responsible for hazards that could affect several districts - Set up disaster protection committees - Set up fire and disaster protection academy - Advise and support communes and districts in fulfilling their responsibilities - Hold disaster protection equipment that goes beyond communal and district responsibilities

Forecasting/Early Warning

General:

The German Early Warning System (EWS) distinguishes between warnings in a defense situation on one hand and warnings during catastrophe events and general hazards on the other. For the former, the competencies lie at the national level through the BBK. For the latter, the states are responsible, such as for flood warnings (based on articles 30 and 70 of the constitution). In short, in Germany, the alarm and response systems are generally decentrally organized during peace times, using subsidiarity principles, with the aim to put those in charge who are closest to the situation and would know best what's needed. In addition, special offices such as the DWD can issue warnings that are part of their subject matter expertise. DWD warns of 12 meteorological phenomena that could endanger human safety and wellbeing, four of which are related to wind and rain[7] : Storms, thunderstorms, intense precipitation, enduring rain. For all of those, level 2, 3 and 4 warnings exist, with 4 the highest (all level 4 warnings are colored in purple irrespective of the phenomenon). A warning level 4 is clearly defined as: ***"The expected weather development is extremely dangerous. Life-threatening situations may occur, creating large losses and destruction".***

7 https://www.dwd.de/DE/wetter/warnungen_aktuell/kriterien/warnkriterien.html).

The Modular Warning System MoWaS

MoWaS has three steps: Warning trigger, dissemination and destination devices.

The trigger comprises the sending and receiving systems in the situation and information centers at national and state level as well as the lower catastrophe authorities at district level that are connected to these systems. An authorized body can trigger the warning systems that are available in MoWaS and reach the population within their area of authority. Is the situation that requires warning larger than their authority, neighboring authorities are informed. MoWaS is intended for where warnings need to be rapidly disseminated to a range of people in an area, otherwise, MoWaS should not be used.

When triggering a warning, the name and title of the warning, the type of warning, the type of event, the warning level, a description of the dangers, the affected area, recommended behaviors and actions, and further information to the population can be issued. The message type can be a warning, an update to the warning, or an all-clear. There are three warning levels in decreasing priority from 1 to 3. The type of warning can be (extreme) precipitation, flooding, flash flooding – in total over 87 types to choose from using pre-defined and standardized event codes.
Using standardized codes instead of plain text enables the transmission of the messages such that in the destination devices the message is available in various languages such as German, English, French, Spanish, Turkish, Russian, Arabic and Polish. There are 136 pre-defined codes for recipients to take specific actions, available in the various languages in the destination devices. Additionally, specific information can be added using freetext space, for which the responsible agencies may have created templates. Finally, the multiplicators need to be selected to which the warning is then transmitted.

The dissemination to warning multiplicators and destination devices comes next. Multiplicators are authorities, organizations and companies such as radio and television who will then transmit the messages to their end users. In the case of radio and television, this could mean interruptions of the current program or showing a news ticker at the bottom of the screen.
In some cases, the transmission still needs manual intervention, but most of it has been automated following the Common Alerting Protocols (CAP).
The CAP allows that multiplicators and destination devices can directly read the messages and display in the desired format. The destination devices that receive the warning comprises all measures which are directly available to reach end users. They differ by information content and by alerting level. For example, sirens currently have a low information level but a high wake-up effect. Warning Apps can transmit more information but might not wake up or alert the end user depending on the type of the application and the user's app settings. For example, in NINA, the user manually can set push messages to "on" or "off" to not be proactively alerted (and would get new information only by manually swiping for updates).

NINA, KATWARN and other Apps are connected to MoWaS. In addition, destination devices comprise national, regional and local, public and private TV and radio stations, online webpages including warnung.bund, an RSS feed, digital city information panels and passenger information systems.

In addition to NINA, an App based on KATWARN is quite widely used across Germany. KATWARN is a complex warning system including an App. It is focused towards communities, where the origin of the system lies, but a wider scope is in use currently, including federal-level warnings. KATWARN is designed to support decision-making, has many user interfaces including wearables, broadcast, digital commercial banners and the KATWARN App. KATWARN was initially developed in 2001 for localized weather warnings, but then enhanced into a multi-channel system for the population. The Fraunhofer Institute was tasked to provide KATWARN to the population by the association of public insurers (VöV) through their societal mandate, who are essentially the operators of the system through the organization “Combirisk”. The history of KATWARN is different from MoWaS, which is a top-down system owned/developed by BBK, and KATWARN is rather bottom-up. There is good cooperation between the two systems, and messages at the warning level (not the information level) for civil protection are exchanged between the two systems based on an agreement, so triggers from MoWaS reach KATWARN and vice versa. Communities are free to choose the systems to warn the population. In the Ahrweiler district, KATWARN is the system of choice.

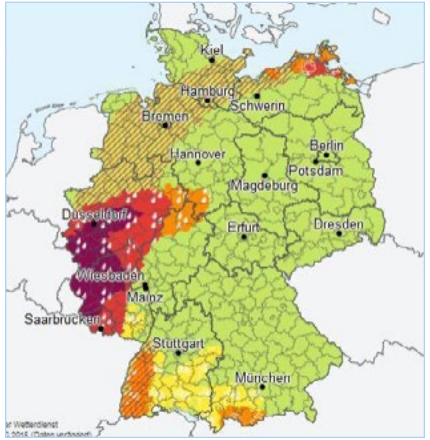
In RLP, the flood forecast and information dissemination is based on the water law and the flood information regulation (“Hochwassermeldeverordnung”). A flood reporting service is operated for the state’s major rivers (Rhine, Moselle, Saar, Lahn, Nahe, Glan, Sieg, Sauer and Our rivers). Once alert levels are triggered, the dissemination is done automatically. For the major rivers, using the historic data and experience, the gauge level observations and the available models and forecasts, almost centimeter-precision in the water level forecast is possible.
For gauges within a smaller catchment, a high-resolution forecast both in terms of water levels as well as the timings is difficult. Therefore, for the remaining rivers in the state, a flood early warning system is run[8]. Both the reporting service as well as the forecast centers are located at the state’s environment office with the exception of the Rhine, which operates its own flood reporting center. If a smaller catchment is forecast to exceed certain flow levels (equivalent to 2-, 10-, 20- and 50-year return period flooding) within the next 24 hours, the corresponding flood level color is applied to the map (green, yellow, orange, red and purple). If the 10-year level is exceeded (orange alert level), the corresponding districts and cities are automatically warned and KATWARN is triggered. There are three channels for flood info dissemination in RLP – the flood information website where the respective geographies on the map are colored according to the alert level, the triggering of alert systems like KATWARN, and emails to the districts, which usually is a central email address then automatically forwarded to all the final community level recipients. In the Ahr in 2021, the third redundancy, the email distribution, failed in July 2021 because of a programming error – it was the first time that a purple level alert was issued. The flood service office stressed it was only this third redundancy that failed, but not the other two. Also for the Ahr river, there are special products available like individual gauge level alerts for Müsch, Altenahr and Bad Bodendorf that trigger emails to the Ahr district distribution emails.

In NRW, the environment office (LANUV) is responsible for the flood information service, while the district governments are responsible for the flood forecast service. The information service’s goal is to inform the population as well as authorities about the current flood situation. LANUV continuously measures precipitation, water levels in rivers and ground water levels. If predefined levels are exceeded, or exceptionally, in case of special weather situations, LANUV creates hydrological bulletins that describe the situation and publishes them on their website, therefore open to the public. Additionally, the intranet of the state administration enables relevant actors to access the information directly. The flood forecast service is located one layer below and is in the responsibility of the district governments. Using the LANUV bulletins and the data from relevant gauges, the service warns communities, dispatch centers for fire and civil protection as well as affected populations and organizations. Details are regulated in the corresponding flood information ordinances. Content to feed warnings into the dissemination mechanism is input at regional or local level depending on each state’s disaster law. The BBK, as one of its services, operates a joint information center (“Gemeinsames Melde- und Lagezentrum GMLZ), where they consolidate all the information received through the channels. The GMLZ cannot take further action unless requested to do so by the states. The GMLZ has three areas of responsibility. It serves as a specialist situation center for topics and events relevant to civil protection, creating up-to-date and comprehensive situation reports, evaluating the events, and informing relevant partners in-country and abroad. Second, the GMLZ is responsible for resource management, coordinating the provision of scare resources at the request of the federal states. Thirdly, the GMLZ acts as a national contact point, processing more than 50 national and international information and warning procedures, activating remote sensing products and acting as the central contact of Germany for international requests for assistance, such as the EU’s civil protection mechanism.

BBK also operates a central, modular warning system MoWaS (see box), which states (and the federal government) can choose to use for the input of and the selection of channels for the dissemination as well as the urgency level of warning messages. Connected to MoWaS is the early warning App “NINA” that is accessible to the general population in Germany to get notifications about warnings. For weather warnings, the DWD feeds the warnings into the EWS. For flood warnings, the multi-state flood portals feed the warnings into the EWS. Currently, according to BBK, NINA has been downloaded by 10 million users (https://www.bbk.bund.de/DE/Warnung-Vorsorge/Warn-App-NINA/warn-app-nina_node.html). At the moment, cell broadcast, the automatic transmission of messages to all cellphones registered to antennas in the affected area, is not (yet) implemented in Germany.

8 https://fruehwarnung.hochwasser-rlp.de/).

The chronology of warnings during the floods in July 2021:
From a weather observation point of view, we (and many others) assess that the weather system "Bernd" and its potentially damaging consequences were forecast quite well, both at the European and national levels. The European Flood Awareness System EFAS had the situation on its radar and provided early, although spatially unspecific, notifications the weekend prior to the floods. The German Weather Service DWD, which is legally required to provide weather warnings to public services and the population, issued their first warnings Monday July 12 at noon.
Their forecast for the West of Germany was for intense, exceptional widespread rain of up to 200 mm to fall on Tuesday July 13, potentially continuing for several days. DWD notified the state flood warning portals and the civil protection services that an unusual meteorological situation was in the making. On Wednesday July 14, when the weather models confirmed the precipitation, an "extreme" warning level was issued for the Western regions in the early afternoon. Anticipatory actions such as the lowering of certain water levels in dammed lakes in the Wuppertal area, for example, were taken. However, the competency limits of the DWD are for weather only; they were not responsible or able to interpret how the precipitation would behave hydrologically in the creeks and rivers.



Source: https://twitter.com/DWD_presse/status/1414524803273400323 / DWD website).

What would happen hydrologically was not clear – how the precipitation from "Bernd" would unfold in the river systems or might cause flooding generally. The RLP environment office was confident that the combination of the DWD weather warnings indicating both strong enduring rain, together with spotty, intense thunderstorm-type intense precipitation and the total forecast rainfall in areas of up to 200 mm together with the information that flooding might be possible under such circumstances, sent a relatively clear warning signal and was the best that could be provided at that time, i.e. before July 14.

The location of where it would rain remained unclear depending on how low pressure system "Bernd" would exactly move and which valley would get the most rainfall. This impacted the hydrological forecasts. The input details in the forecasts were ever changing, sometimes the bulk of the rainfall was localized more southerly, and then again more northerly. Only in the morning of Wednesday July 14 did it become clearer where rainfall was likely to be most intense and that the Ahr watershed in particular might be hit. Even then, it was ultimately the particular way rainfall was distributed in space and time that allowed the event to unfold as it did. For example, in the Westeifel region there was a lot of initial rainfall; toward the end of the event there was another intense precipitation phase, with 20 mm of rain per hour falling for 3 hours continuously. This turned out to be quite bad for the Ahr valley. Together with the West-East orientation of the valley, which channeled much of the rain in the north from the slopes down into the river, this led to a rapid increase of water levels that was hard to forecast.

The RLP environment office issued a press release on July 14 with seemingly a focus on their flood reporting center information, stating that the event's focus was on the Rhine and the Moselle with an expected 2–10 year return period flood condition, but that no extreme flooding was expected in those main rivers. The message also said that the smaller catchments could react swiftly, too, and that preparatory measures such as sandbagging would be advisable. This could be, and perhaps was, easily misunderstood to mean that no extreme flooding was expected and also that there was limited detail available as to the smaller rivers. Later that day the LFU issued gauge level alerts for the Altenahr gauge station using KATWARN. This was in response to a very dynamic situation in the weather models, where small changes in the expected areas of most intense precipitation had a big impact on the forecast result. This was confusing for local actors monitoring these gauge predictions. Only on July 15 did the LFU release two more press releases that began to clarify how dramatic the situation was, still without providing a clear picture.

Our own analysis indicates that the first warning of intense precipitation was triggered in MoWaS on **Monday, July 12** in the afternoon by Euskirchen district, warning of up to 200 mm rainfall, outlining potential local flooding. On Tuesday, July 13, no warnings were triggered in MoWaS. On **Wednesday July 14**, during the course of the day, more and more warnings from rain and flooding were issued. Up until ca. 18:30, these were limited to the northern part of the ultimately affected regions, in particular Düsseldorf and Hochsauerland district, at warning levels 2 and 3.
After 18:30, further warnings were triggered in the southern part (Rhein-Sieg-Kreis, Euskirchen, Trier district). For the Rhein-Sieg-Kreis, this was directly at warning level 1. Until 1:00 in the night to July 15, a sequence of further warnings was triggered in Wuppertal, Solingen, Trier, Vulkaneifel, Bitburg-Prüm, Bernkastel-Wittlich, and Trier-Saarburg. In total, 16 warnings reached the highest level, 1.

Overall, for NRW and RLP from July 12-20, 2021, 145 warnings and their updates were triggered in MoWaS.

Of the 145 warnings, the most (31) warned of flooding (Überschwemmung), followed by high water levels (17) (Hochwasser) and strong precipitation (17, Starkregen). A good number used the unspecific category "warning" and then specified the flood conditions in the free text field, which however undermines the systems' event code capabilities so the automatic translation does not work. Of the available content codes for behaviors and actions, surprisingly many only used one or two instructions, especially “Get information from the media, for example on local radio”, and “Give the affected area a wide berth”, which in hindsight are quite unspecific and inappropriate to the flood situation encountered. Even at warning level 1 for Solingen-Wuppertal and Trier, only these two actions were advised. In contrast, some warnings contained no less than 18 actions, some of which were confusing or contradicting. Finally, some of the warnings used available templates for the text fields, but did not fill in the blanks, such as “contact (fill in contact point)” were left unedited. Overall it can be said that the familiarity with the system and the competency of system use could be improved in many cases.

In NRW, in many cases state-wide media such as Radio NRW & WDR and regional media such as Energy, Epost, Madsack, Antenne AC etc. were reached. In RLP, there were no state wide radio / TV channels reached. In RLP, the SWR, which has a wide reach, never received the warning level 1 message from Trier to immediately disseminate throughout their programs. Instead, radio Energy and Madsack received the warning, despite not having any studios in the state. Similarly, national public radio in Germany (Deutschlandfunk, DLF), did not receive any level 1 warnings, though it did disseminate the national and multi-regional weather warnings. As a national program, DLF has agreed with the authorities to transmit national warning messages. However, despite two states being affected, the EWS seems not equipped for this type of national warning message – there were only regional and local warnings, which do not reach the DLF unless it is manually added to the dissemination list by the local and regional authorities.

It was later discovered that the compilation of the lists for media recipients had been partially wrong due to misinterpretation or outdated entries, and amongst others, the SWR was not on that list. This highlights gaps in the warning chain between the corresponding civil protection authorities compiling the lists, the broadcasters who should then follow instructions how to disseminate the warnings (as an example, the instructions said “interrupt your radio and television program for this message” - but no such radio or television stations were on the list), and reaching the population. Further recipients comprised the BBK, the GMLZ, the dispatch centers in neighboring locations, the national warning central and the civil protection contact points. All connected Apps incl. NINA and KATWARN were recipients of the warnings.

Surprisingly, no MoWaS warnings were triggered for the most affected district, Ahrweiler. The reason is that the system of choice here is KATWARN, which did issue three warnings and one information at Ahrweiler district level, but due to an error these warnings were not transmitted to NINA. The underlying issue seems to be that no “test” functionality to check whether a message issues in KATWARN reaches NINA is built in, which is supposed to be corrected soon. Furthermore, the integrated dispatch center in Koblenz, also responsible for Ahrweiler, did not warn through MoWaS, although it should have been clear based on the thousands of emergency calls received that a disaster was ongoing. The dispatch is not allowed to issue a warning on their own, and a written request to issue one was not received from the responsible emergency response leader in Ahrweiler district.

For KATWARN itself, the ZDF researched that on Wednesday July 14 before noon, a specific flood early warning for the Ahr and its tributaries was sent to roughly 22’000 people. The App warned of “rapidly increasing water levels with flooding within the next 24 hours”.

The LFU gauge level forecast at Ahrweiler repeatedly changed, from 3.27 m to 5.19 m, down to 4.06 m, up to 5.3 m and to 6.81 m over the course of less than 5 hours, culminating in the gauge washing away. At that time, the gauge reading was 5.75 m, the last measurement transmitted before the station stopped working.

Later that evening at around 23:00, the district Ahrweiler issued the following warning via the KATWARN App: “Citizens of Bad Neuenahr-Ahrweiler, Sinzig and Bad Bodendorf living within 50 m left and right of the Ahr should leave their apartments”. The 50 m proved to be an underestimation - in the Lebenshilfe nursing home in Sinzig, twelve people drowned in the floods later that night. The home is located 250 m from the river.
None of the warnings, whether from the weather or flood authorities, the local districts or those in the news, transmitted the sense of urgency or a sense of immediate danger to life safety clearly warranted in hindsight – none of the messages said: “Immediately seek higher ground as a safe place to prevent drowning”.

For many it seemed unimaginable that the actual flood extent and flow velocity could be so much above what was in the official flood hazard maps, outlining the HQ100 and HQextreme flood extent. Warnings which included unusually high predictions of gauge levels were doubted or assessed as erroneous in some cases. In particular, in the Ahr valley residents discounted the forecasts, assuming the floods wouldn’t be worse than the 2001 and 2016 floods of record. This highlights the risk posed in calling disaster events ‘exceptional’ or ‘unprecedented’ - it limits our imagination and increases our risk.

What happened in Stolberg.

The city of Stolberg with its historic city center has suffered flooding in the past, including in winter 1966. On July 14, 2021, the streets in the center turned into raging torrents once more as the river Vicht left its bed. Based on the weather warnings, the "flood" working group had already met at the fire station on Tuesday July 13. They were aware of their vulnerable locations and had called ahead to all nursing homes and industrial facilities to inform them about the extreme rainfall that had been forecast. Early in the night to Wednesday July 14, they dispatched the crisis committee and notified the population about critical water levels. Response vehicles with loudspeaker patrolled the streets, advising people to not go to basements but stay safe in upper floors. In the early afternoon, they closed down the streets in the city center and prepared for evacuations. The mayor issued a video statement later that afternoon, and a little thereafter self-evacuation of the affected areas was advised by the authorities, also providing information on which shelters would be open. Then authorities helped those that could not self-evacuate. They continued patrolling the streets with loudspeaker announcements until nightfall. At this point at night the water had risen so high it became too dangerous to evacuate, so the advice was limited to seek safety in upper floors but not leave the homes anymore. They declared the disaster state during the night to July 15, and the regional level "City Region Aachen" crisis committee provided support. The next day, the extent of damage became recognizable, including schools, day care facilities, fire stations as well as the town hall, and dozens of kilometers of streets. While the safeguarding of the population was a success, property damage was immense, in particular to public buildings.

The entire plant and electricity installations of town hall were irreparably lost, rendering the building unserviceable. And like elsewhere, rebuilding is tedious and financial support payouts are slow, following long discussions as part of the approval process. And unlike the Ahr valley, where energy and heat was restored or at least temporary solutions provided swiftly, there are reports of people spending cold winter nights in their partially repaired homes without the heating replaced yet.

Response

How the early warning was (mis)interpreted, leading to wrong action, late action and inaction

As discussed above, early warning both for the weather and the developing flood situation was provided in various detail and accuracy, although with some challenges and problems. But to lead to far-ranging action, the warnings must be received, understood, trusted and heeded by the actors of the lower civil protection and fire brigade forces, the aid organizations and the general population. It seems it is here that the real problems began, especially for the Ahr valley.

The main challenge seems to have been putting the forecasts and early warnings into local context, i.e. understanding what 150 mm or 200 mm of rain or a gauge level of 6 m might mean on site, and what appropriate preparation and response measures should be taken. We identified a gap, a lack of interpretation provided regarding what technical meteorological or hydrological forecasts signify. Weather, water and upper civil protection authorities that either issue or receive the warnings first-hand underlined that their lack of local knowledge prevented them from providing more concrete guidance or interpretation what problems could occur or what damage could be sustained from the respective rainfall or gauge level that was forecast. They indicated that such an interpretation or contextualization task was the responsibility of the local authorities and/or the local first responders – in other words, the interpretation of a gauge reading should happen locally. Conversely, we also repeatedly and clearly heard from those local authorities and first responders that they also were unable to interpret the technical weather and flood forecasts, since they do not have a corresponding education or qualification in meteorology and hydrology and hence were unable to say how local soils would behave after 200 mm of intense rainfalls, or where this rain would turn into problematic flooding, or how a river would behave at a certain gauge level. They might have some limited historic comparison by looking at what gauge levels had been in prior floods, but that this was not equipping them with the actionable advice they would need to better anticipate the situation.

Some confusion was also caused by the colors and labels of the warnings that were sent out. For the weather warnings, the highest warning level is the color purple, but it was found hard to distinguish between a purple thunderstorm warning, which happens relatively frequently in hot summers, and a purple persistent rainfall warning, which is very unusual. People only saw the purple warning from DWD and automatically assessed this as a usual thunderstorm warning, not noting the difference.

Where local authorities did activate alarm mechanisms such as the remaining alarm siren infrastructure that had not been dismantled since the end of the Cold War, or where they used mobile infrastructure such as loudspeaker announcements from official response unit vehicles, they were often not heard, not heard clearly enough to understand the message or whether the message would apply to them directly, and therefore did not lead to immediate action, either. Many recounted the situation that they briefly did hear the loudspeaker car drive through the streets but assumed it was meant for the population closer to the river. They could not believe that the authorities really meant to evacuate residents living on these roads since no one alive today had ever seen them flooded before.

Another challenge was in the way warnings were interpreted if they were interpreted at all. People simply did not believe a flood of this magnitude could happen. Especially in the Ahr valley, where the relatively recent experience of the 2016 flood had been communicated as an “exceptional”, “100-year flood”. The 2016 flood was seen as the benchmark of the worst that could happen. Because the 2016 flood had not resulted in any fatalities and could be – or could have been – managed by many affected people using simple protection measures such as moving valuables out of the basement and upstairs and tightening unprotected openings e.g. using sandbags, those were the precaution measures taken. Fire brigades opened sand bagging stations and handed the sandbags out, and community workers started inspecting and cleaning the gutters so any excess water could flow off easily. Those who received the weather warning believed it was one of the usual thunderstorms, and those who got the flood warning dismissed it as meant for others, for those living closer to the river, those in immediate sight of the riverbanks. People felt they were actually prepared for what was about to happen – a repeat of the 2016 floods. A poll by Thieken et all (2022) revealed that of those who received warning, 85% did not expect a very severe flood.

A proportion of the fatalities was due to wrong behaviors, especially those that occurred outside of the massive destruction zone in the central Ahr valley. Many people tried to salvage items stored in the basement or tried to move their car from garages when they realized they were about to be flooded, and then got trapped and could not get out anymore.
Many seemed to be unfamiliar with flood situations as they had not experienced them before.

The river floods took hours, almost days to fully unfold from the upstream catchments. The fire brigade in Adenau was dispatched for the first time on **July 14 at around 13:00,** when everything was calm and quiet further downstream. At 14:30, the water level in Altenahr was rising but still only at 1.38 m. It took the rest of the afternoon to surpass the previous, 2016, record **at 19:30**. This represents six hours’ time during which the catastrophe was moving slowly downstream from Adenau in the upper Ahr valley to the middle valley, reaching the lower part near Sinzig only **towards midnight.** It is hard to understand how no information about what was going on upstream was received in the downstream areas, neither formally through an emergency communication protocol, nor informally by calling colleagues in the administration or first responders. Such relatively informal but institutionalized “telephone chains” seem to be in place elsewhere and found to be useful, for example in Mayen-Koblenz district, where an upstream community is required to call the next two places downstream according to their alarm and dispatch plans. In the Ahr valley,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such a communication chain did not exist. There were few eye-witness posts on social media, but they seem to not have triggered any understanding of what was really happening in a wider audience. As an example, a fire brigade did post that they were evacuating their own fire station and moving to a multi-purpose hall, which then later also flooded. However, rather than take this as a sign that the flooding was moving from extreme to out-of-control, it appears people thought this was due to special circumstances upstream and that the water had enough space to spread out harmlessly in their downstream area; that nothing bad would happen.

A consistent message that we heard from our interviewees was how unbelievable, how unconceivable, how impossible it had been to see the flood of this size and its consequences. When asked about the historic floods of 1804 and 1910, some people had heard of it but could not translate it to their current environment and what consequences such a flood would bring, but mostly the historic flood events and their devastation had been completely forgotten, despite being a very remarkable event that had been discussed and described extensively, as historic documentation proves.

How the event unfolded over the first few days – the chaos phase

It does not come as a surprise that the immediate hours and days after a disaster event are often chaotic and uncoordinated. On top of a "regular" chaos phase expected in a disaster situation, the immediate problem here was the inability to communicate and hence get a proper overview of the situation. Due to the extent and severity of the damage, critical infrastructure including power and telecommunication had failed, too. The second big problem was access, especially in the narrow Ahr valley, where 103 bridges were destroyed including many newer and big bridges and major highway connections like the B9 road bridge.

As flood impacts escalated, response unites successively escalated the emergency alarm levels; the district fire and civil protection inspectors (BKI) or the district fire chiefs (in RLP and NRW, respectively) took over operational control, complemented by applying the respective alarm and dispatch plans (AEP). Many of the districts, however, did not have corresponding plans in sufficient operational detail or not ones that had been developed with a flood scenario in mind. It is evident that there is a strong correlation between the staffing capacity / the level of professionalism in the units and the availability and usability of those plans. Consistently, we have heard that volunteering forces where even the BKI is a volunteer function suffer from significant capacity constraints so that understandably specific, well thought-through plans cannot be developed and where emergency dispatch is done based on experience only. Conversely, where a professional, full-time position is available usually the plans were present and at a higher level of detail and granularity. For small-scale, regular events this lack of capacity doesn't heavily impact a units' ability to provide the services needed; acting based on prior experience is sufficient. However, for a situation like that experienced with Bernd, having no experience with an event that size to fall back on, and no plans or protocols to follow in the absence of experience, meant units were quickly overwhelmed and un(der)prepared.

For example, a big focus of almost all fire brigades was manning sandbagging stations and distributing and installing sandbags at neuralgic locations in their intervention areas. This was useless in most cases in this size of flood. It was not recognized that the action taken was based on an entirely different scenario than the one materializing. Even worse, in many instances we were told that procedures were still adhered to in cases where they obviously were already inadequate for the situation at hand and where flexibility and resourcefulness would have been far more effective than protocol.

It was also reported that thinking in wrong scenarios was not only evident at the official civil protection level, but also at community or individual institution level. What gets practiced regularly is the fire drill. As an example, nursing homes or medical services know how to go down and get out. What's not been practiced is the flood drill – evacuate early or then safely move upstairs with your key belongings and emergency supplies (see box on Stolberg earlier).

Many local responders found a situation on scene that they too were helplessly exposed to. In many cases, fire brigade equipment and vehicles or in some cases entire fire stations were flooded. Generally, the floods were so violent and the water levels so high that any immediate action was not possible – suction pumps that usually serve to pump out flooded basements were equally inadequate as the sandbags that had been prepared, and many told us that there was nothing to do but wait until the water started receding. Sending rescue swimmers and boats out was too dangerous. An additional problem was that most fire brigade staff, especially the volunteers, live locally and therefore they were significantly affected themselves, their own houses were destroyed, they lost friends and neighbors. More difficult was the psychosocial situation for the emergency service workers operating outside of the immediate devastation area but receiving live accounts of what was happening in flooded houses, leading to traumatization of emergency services workers as they accompanied people on the phone during the night in hopeless situations, sometimes until the callers died.

It remained difficult to get an overview of the situation – mostly for the first few days but in some areas this went on for weeks. Anecdotally, communities located along the steep narrow tributaries like the Sahrbach, upstream in the Ahr valley were only reached for the first time several days after the flood and a clear overview of the situation and a needs assessment of the population was not conducted until weeks after the flood. Even for any help to arrive to start shoveling mud, clearing out debris and providing immediate necessities it took several days – too long for the affected people who sometimes had nothing. Especially the upstream communities felt remote and isolated and felt they received unequal response aid compared to the downstream communities which were reached first. There were recounts of the eventual evacuation of affected nursing homes, with the elderly wearing nothing but diapers. In needs assessment carried out by aid organizations, it was found that several scenarios including the elderly needing diapers had not been considered, and material available for distribution for example only comprised children's diapers.

The size of the disaster event made it hard to adequately respond. The Ahr valley had turned into a disaster zone 40 kilometers long overnight. Hundreds needed to be helped at their houses or locations where they sat out the flooding. On Thursday July 15, the district Ahrweiler was assuming that roughly 1300 people were missing and 3500 had been placed in temporary shelters. We heard across the event, from the Ahr valley, from Rhein-Erft district and elsewhere, that search and rescue was ad-hoc and not equipped for what was needed. It was unheard of that German citizens had to be rescued using diggers and wheel loaders and then transported to shelters in tractor trailers and open cargo beds of trucks instead of designated equipment. Winching helicopters were desperately lacking. The guidelines and the subsidy requirements for equipment are not adapted to the needs in deep floods, such as off-road and amphibious abilities of vehicles.

Thousands of people needed assistance. Aid organizations sheltering people reported their modules were for 50 people but had to host up to 700 under really difficult conditions – no power, no running water, no wastewater connections for the restrooms, that was an immense and difficult task not covered in the education. As part of the chaos phase, people needing assistance and those directing the streams of people were unable to differentiate and hence everyone was just sent somewhere – those needing medical assistance ended up in shelter location, and those needing only shelter showed up where medical assistance was provided. Experts reported that the training and operation manuals were not meant for this type of disaster, in which a spatial triage and separation of functions was no longer possible.

As outside help from other German states and neighboring countries reached the affected areas, the logistics and coordination tasks became important but were overwhelming, too. Initially, for the Ahr valley, the Haribo central warehouse in Grafschaft near Bad Neuenahr-Ahrweiler served as a hub for the units but soon turned out to be too small and lacking necessary technical facilities. Later, a much bigger "ready room" was found at the Nürburgring race track, where helicopter landing spaces as well as room for several hundred aid and technical vehicles from the German Army, the THW, fire brigades and GRC units from other states. The location could also host 2000 personnel. Storage buildings could be used to receive the tons of aid material that was provided or donated. The "flood aid base camp" at the Nürburgring track was in operation until mid-August. Elsewhere, similar approaches were used, such as in Euskirchen, where a large corporate warehouse space served as storage for the donated goods. Many goods donated overall were found to be not useful.

Organizing these central aid camps logistically was difficult because of the size of the operation and compatibility issues. Due to the federal and decentral organization of disaster response, each state is organized differently. When response and aid units (with exception of the THW, which is a national agency and modularly but homogeneously structured across the entire nation in Germany) arrived, it was unclear what size a unit would have, what technical capabilities they were equipped with, and how to integrate them into the communication due to different radio equipment. There was no easy way of finding out such as referring to a nationally accessible database or guidebook – everything had to be manually requested, leading to delay and the dispatch of units not equipped for a task. We also heard the opinion that this absence of transparency may be intentional in a federal structure, as to not reveal what one is capable of towards other units or states. But such a lack of transparency was an obstacle for reacting swiftly and dispatching what was needed to where it was needed.

Another issue was the lack of organized or practiced command structures in a disaster. It would have been ideal if local response leaders such as the district BKI could have been empowered to keep working as the lead in managing the crisis, bringing to their task the knowledge of what was needed on the ground and what the local specific conditions were. The auxiliary support provided by higher levels or out-of-state units would provide a layer of support by handling logistics, providing reinforcements in the back end, organizing equipment and personnel that was needed for a specific job. Local knowledge is critical in providing appropriate support, such as knowing what size of truck can enter a specific location (we heard of foreign units bringing large equipment into what they thought was a street but found out it was a narrow alley, etc.), how to access an area that may be blocked by water, debris or landslides, or how to best approach a specific situation locally. Local crisis managers would have preferred that this "indigenous knowledge" be used by the auxiliary support.

Instead, it was found that auxiliary units were stepping in and duplicating tasks, then getting lost or stuck, and often they were taking away the responsibility in the hope or belief they could do that job better. This not only caused confusion but also frustration – we were told multiple times that the rural communities in the initial days self-organized the help using the local forces, and that this worked much better. Such a local baseline structure needs to be kept up, and then supported by the auxiliaries. Auxiliary support often could not act on order of the local coordinator but had to get their orders from within their own organization, from a decision-maker who was not on site. This further delayed action on the ground and often caused miscommunication, where an urgent, local request was not fulfilled but rather something else implemented that was neither urgent nor high priority. This was also partly because support was not based on the demand but rather what was available on the "supply side", showing off what one was capable of in that respective area rather than taking on tasks that needed to be completed. As a consequence of bureaucratic issues, complex requirements to discuss across district, state levels and across organizations, and the lack of functioning official communication channels, we were told that many requests and decisions were eventually taken outside of official communication and reporting channels as it sped up decision-making and got results to where needed the most.

Because the initial response was so uncoordinated, much of the response was inefficient and pushed other problems "downstream", e.g. instead of cleaning out the muck as a first priority, other tasks were taken up and the muck started to harden, which made it more difficult to get it out and caused subsequent damage. Similarly, rather than directly getting rid of damaged goods as they were removed from flooded properties, they were left on the streets. This meant a new task needed to be created to transport them off, because the blocked streets caused traffic jams and access problems.

Where externals were tasked with specific jobs, such as providing intelligence and local needs assessment, the lack of communication structures and a coordinated hand-over mechanism between forces that came off duty and the next forces meant that the same tasks were carried out over and over again, the results not communicated to where they were needed, and then repeated again. This was not only felt within the response organizations and the crisis managers who needed to get an overview of the situation, but also within the population, who was asked the same questions multiple times by different responders and felt confused and hopeless as to why this was happening. Overall, it was felt that the initial support provided was ineffective, slow and not well coordinated.

Contamination, especially with heating oil, and to a lower extent from destroyed or damaged sewage plants, remained a big issue even months after the initial response phase. In the initial response, the fire brigades and the THW have pumped over 1.8 million liters of oil/water mixtures from buildings in the Ahr valley. The discovery of a higher extent of oil contamination than anticipated was one of the big shocks for homeowners, some of which often had already started to rebuild when the difficult decision had to be taken that due to oil contamination a property still had to be condemned.

Besides the "formal" aid and support structure, there was a massive influx, some called it another "flood", of spontaneous, private volunteers, as had been seen in prior disaster events like the 2013 floods where the self-organization through social media was a new element to be considered in the official response, as discussed in the corresponding PERC report. Given the nature of the event especially in the Ahr valley, the coordination of private volunteers was even more difficult this time. In the first days, the arrival of volunteers was so large in numbers and the officials apparently caught unprepared that the access roads were blocked to the extent professional responders got stuck in traffic jams, notably those with urgently needed heavy equipment to clear debris, or bring heavy items to install temporary river crossings. Ultimately, the crisis coordinators had to suspend private volunteering access to the valley and restarted such aid work when a volunteer shuttle was organized to bring the volunteers from Koblenz or Grafschaft central locations to the Ahr valley to places they were needed. The organizers of this shuttle, which is still operating and brought over 100'000 helpers to the valley within the first 6 months, were honored with the State Cross of Merit. Once the volunteering help was controlled a bit better, they were very agile, organized and swift in carrying out any task handed to them. We heard consistently from the affected population as well as local politicians that without this private help, the Ahr valley would have been completely lost. There was and still is a very high level of gratitude among the population for the often menial, tedious and tiring work they completed – cleaning out the muck from basements and flooded living areas, hosing down belongings and content that was salvageable, organizing necessary tools and machinery such as hoses, water containers, small tractors with trailers, mobile power supplies and much more – things that were unavailable or too time consuming to get through official channels.

One downside of the influx of volunteers was the parallel influx of fake news, a politicization of certain topics by radical groups that had emerged or strengthened during the COVID-19 pandemic and the swift, far reaching dissemination of such thoughts via social media that kept the administration and local politicians unnecessarily busy and made them feel bullied with another problem on top of the flood disaster. How both the support of the private volunteers as well as the interaction with representatives of this group felt in the perspective of a local resident is described in a book by Andy Neumann[9].

Critical infrastructure

With the bridges failing, additional critical infrastructure such as heating gas and drinking water distribution failed, as piping of those utilities is often connected to the bridges to cross the river – when the bridge fails, the entire utilities fail alongside it. In RLP, 7'220 of 8'000 gas connections in Bad Neuenahr-Ahrweiler alone were destroyed or damaged, and more along the valley floor. But the failure of critical infrastructure did not stop within the flood damage zone, but had further ramifications all the way up to the hills outside the valley, including Grafschaft community.

The failure of communication infrastructure made a coordinated response impossible in the first days: the mobile network failed, the digital radios used by response organizations showed incompatibilities between different state organizations and failed completely in the upper Ahr valley whereas responders had initially been told that the digital communication infrastructure for first responders was battery-driven, autonomous and operable but still often failed. Trying to set up communication channels often meant climbing the hills to hope for a signal from a different cell, which was spotty and time-consuming. In some cases, messenger services like WhatsApp worked as the only communication means because they only require minimal bandwidth and work asynchronously. Until communication infrastructure had been permanently restored, the GRC provided support with radio telecommunication and central WiFi hotspots in affected locations. It took two weeks to restore the prior coverage fully again in RLP through the installation of emergency communication masts. It took one month for most of the network to be restored to pre-disaster service, and four months for broadband to be restored in the most affected areas.

9 Andy Neumann: Es war doch nur Regen. Gmeiner, 2021.

In NRW, in the heavily destroyed town of Bad Münstereifel, it took five days to restore the drinking water supply after the flood event (most frequently through emergency tanks), and about 50% of the city center was re-connected to the fresh-water network shortly thereafter. However, water had to be boiled before consumption until about one month later. In RLP, it took until early October until the drinking water supply was restored in Altenahr and Lind. Until then, the GRC was providing emergency supplies. Sewage treatment plants in Altenahr, Mayschoss and Sinzig have been largely destroyed and it is unclear how long their reconstruction will take. The GRC is operating three temporary wastewater treatment plants in the Ahr valley that are planned to run for 3 to 5 years. Originally, this technology was developed, in collaboration with the IFRC, for use in international operations in low-income settings (e.g. in Bangladesh). This is the first time they have been used domestically in a high income setting with a rigorous regulatory framework.

There were and continue to be many road closures in and around the Ahr valley. In the Ahr valley itself, about 40 kilometers long, there are roughly 70 kilometers of main road network. All of it was affected one way or the other, and roughly a quarter completely destroyed. The interruption of the main highway arteries A1 and A61 near Erftstadt hit an area of high traffic volume. It took until end of September until the southbound part of the A61 could be reopened, and until Christmas for the northbound part. The A1 was only reopened at Easter 2022. Besides the road network, trains were also heavily impacted. Over 600 km of track was affected in NRW. The Cologne–Wuppertal–Hagen–Dortmund and Cologne–Bonn (Main Central Station)–Koblenz lines were closed. The Cologne–Bonn and Beuel–Koblenz line remained open, but trains were subject to delay and cancellation. Customers were asked to avoid travel within and to NRW by train. The train connection from Dresden to Prague was also suspended after mudslides buried the tracks. Along the Ahr Valley Railway at least seven railway bridges were destroyed. In RLP, the Ahr and the Eifel routes are destroyed. Deutsche Bahn estimates that the Eifel track can be repaired until the end of 2023.

What can largely be counted as a success is the performance of the large dams. Despite exceptional water volumes, they mostly performed as designed. Earlier, experts had voiced concerns on 15 July that the Steinbachtal Dam upstream of Euskirchen was unstable and could fail; 4,500 people were preemptively evacuated from parts of Euskirchen and later several thousand more from parts of Rheinbach and Swisttal. Drones were deployed to inspect the dam; while no cracks were found, the situation was still treated as critical for another few days. Several other dams in NRW, including the Rur Dam, overflowed but without concern for their structural integrity. One of the few failures was on July 16 when a dam of the Rur near Wassenberg failed, prompting the evacuation of Ophoven.

Recovery

It was generally difficult to move from the initial response phase to a more organized and pre-planned recovery and ultimately reconstruction phase. Given the size of the event and the extent of damage, needs remained very varied across the geographies and hence pace of progress was very different. It was particularly difficult for the aid organizations to transition out of the emergency response with an official mandate and during a time when there was a hand-over from the crisis committees to the administrative units. Especially the needs for the elderly, the most vulnerable and for social and human support remained high even in the recovery phase, and it was simply not part of the mission statement of aid organizations to stop and return to normal, so they tried to find a practical mode where these needs could be satisfied despite transitioning into a new post-disaster phase.

Financial support for recovery

The national and state governments moved quickly to promise and then organize financial disaster recovery aid. The national government put in place a state secretary committee "National flood aid" as of July 21, 2021 to discuss and coordinate the basics for government immediate disaster assistance and reconstruction aid. **For immediate disaster aid,** the national government decided to contribute with up to EUR 400 million to the states' disaster aid programs, the declaration for which was signed on 30 July 2021. For the mid- and long-term **recovery and reconstruction** financial needs, to cover uninsured losses and provide immediate financial support for those most in need, the German parliament agreed on a fund (Aufbauhilfe 2021) with a total volume of EUR 30 billion. Of that, EUR 2 billion are used directly by the federal government to repair and reconstruct national infrastructure, while the rest is distributed between the most affected federal states of NRW and RLP plus the lesser affected states Bavaria and Saxony.

A reconstruction support law (Aufbauhilfegesetz, AufbhG 2021) regulates the national solidarity fund (Aufbaufhilfefonds 2021), providing the legal framework to organize reconstruction and the split of the funding. The fund is available to support reconstruction for privates, commercial entities and other institutions as well as for the destroyed public infrastructure. The German Parliament (Bundestag) put this law in place on Sept 7, 2021. The funding distribution between the states is regulated in the reconstruction regulation (Aufbauhilfeverordnung, AufbhV 2021). Furthermore, a new article 246c was introduced into construction law, facilitating in certain cases the installation of certain mobile construction and infrastructure. This article was specifically put in place to aid with the limited reconstruction space in affected areas and to allow the temporary erection of so-called "tiny homes", in particular in the Ahr valley where they have been located in the communities Bad Neuenahr-Ahrweiler, Sinzig, Grafschaft and Altenahr and serve as temporary homes for the most affected flood victims. In total approx. 170 tiny homes were donated and installed in the flood affected villages and cities. The article's operation is limited to a duration of 5 years following the flood.

The recovery fund also covers the emergency relief already paid out by the states of NRW and RLP directly following the event. NRW has set aside EUR 300 million for emergency relief and has so far paid out EUR 102.4 million to private households, EUR 35.7 million to businesses and industry and EUR 65 million to local authorities. RLP has paid out EUR 35.3 million to private households, EUR 13.1 million to businesses and


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industry and EUR 118.9 million to local authorities. The damage threshold to be able to claim money for emergency relief were set to EUR 5000 per household or business with the possibility to reduce the threshold to EUR 3000 in case of hardship.

In RLP, the reconstruction support fund law (Aufbauhilfe-Sondervermögensgesetz AufbhSVLG) regulates the basics for reconstruction aid in the state. It was put into effect on 1 Oct 2021 and organizes the financials for the reconstruction. Applications and payouts for private and commercial entities (not for the communal infrastructure or agriculture) are handled by the ISB, usually responsible for supporting the economy and housing programs, whereas in the overall reconstruction process they are one element of many, coordinated by the Ministry of the Interior and the reconstruction committee. The ISB is not involved in other mechanisms such as subsidizing a more sustainable heating or the measures for flood protection or other areas, as they are not their main area of competence, and they would not have this additional capacity.

Reconstruction support is available for up to 80% of the property value for locations damaged in the 2021 floods. Donations and insurance coverage are usually calculated into the 20% deductible and not into the 80%, so in theory compensation can be as high as 100% but then capped.
The property flood damage must be confirmed by the community and the extent of the damage independently audited by an architect or an engineer. The architects and engineering associations in RLP have published a list of qualified experts. Initial 20% payments can be requested in advance to expedite reconstruction, for example start important repair or drying measures. Applications have to be made exclusively online, but infopoints in the Ahr valley as well as in Trier are available to support citizens in filling them in. For content damage the compensation is similarly run through the ISB but are based on fixed sums of EUR 13’000 for the first person in a household, EUR 8’500 for the second, and EUR 3’500 for the third and every additional person in the household. Partial content damage leads to pro rated fixed sums.
Content and property applications are handled completely independently given their different nature (actual value versus flat sums paid out), which helped expedite the entire process for the household contents. At the time of writing, ca. 11’000 completed applications related to privates, and ca. 300-350 to commercials. There is roughly a 90/10 split between content and building applications for the private track. It is reported that currently 95% of all submitted household content applications have been completed, and roughly 55-60% of the submitted property applications.

Damage to schools has been assessed as more than EUR 100 million in the Ahr valley alone, and 14 schools were rendered inoperable even after the summer school holidays. The really good news for the students was, however, that alternative solutions were successfully found. We were told that all students had a place to resume their education, whether in temporary school containers put in place, or going to other schools in the vicinity, after the summer holidays. Additionally, to bridge the holidays and avoid children having to live through the initial chaos and recovery phase, summer programs were immediately organized to ensure parents felt their children were taken care of, and to provide children with opportunities to get their mind off of what they had just lived through.

Similar provision of adult mental health, however, was weaker.
The psychosocial emergency support (“Psychosoziale Notfallversorgung PSNV”), provided was felt to be inadequate. According to RLP disaster law, the districts are responsible but lack minimum standards, and a large variance in support capacity was found. There should be minimum requirements created for the size of the PSNV units as well as their offerings, and for the educational requirements at a state if not national level. Aid organizations like GRC have provided such PSNV services due to the high demand and because they had the expertise in-house.

Insurance:
In Germany, elemental insurance cover that would provide financial compensation after natural hazard events, or individual coverage like flood cover, is not mandatory. According to a 2021 study by the German Insurance Association GDV, only 46% of properties were financially protected against natural hazards through insurance at the time of the event – at the end of 2021 the number had already risen to 50%. In the states most affected by “Bernd”, a GDV infograph shows that the coverage in NRW is about the German average at 47%, but much lower in RLP at 37%.

However, these low numbers should not be interpreted to indicate that floods and other natural hazards cannot generally be insured. Insurability and insurance penetration should be looked at separately. From insurance experts in the German market, we understand that there are only a few outliers who pay very high flood premiums. The majority of properties can obtain fully affordable flood insurance cover.
Where properties sustained prior flood losses and even for extreme cases where flood premiums were quadrupled since, the flood coverage still is in the low four-digit Euro range. This can further be customized by choosing different deductibles ranging from a few hundred to a few thousand Euros. The low insurance penetration in Germany is indeed not explained by new business, where some 90% of properties take out elemental cover, but rather by existing, in-force, sometimes old contracts (generally before 1994), where the lack of elemental cover is not corrected, also due to a lack of risk awareness of the insureds.

New discussions around mandatory elemental coverage have flared up, like they did after past floods, e.g. through the justice minister’s fall 2021 conference request to review such a mandatory coverage. The GDV has published a position paper, discussing the option (and willingness by the insurance companies organized within the GDV) to not make elemental coverage mandatory, but rather require that flood insurance always be offered (mandatory offering as opposed to mandatory buying).
The population could choose an opt-out mechanism if they don’t wish coverage, but only after signing a waiver to ensure no indemnity is then made by either the insurance industry nor by local, state or national governments. This would ensure that no unfair, undue ex-post compensation is provided. Such ex-post compensation can act as a disincentive to ex-ante financial protection like insurance. On this basis,

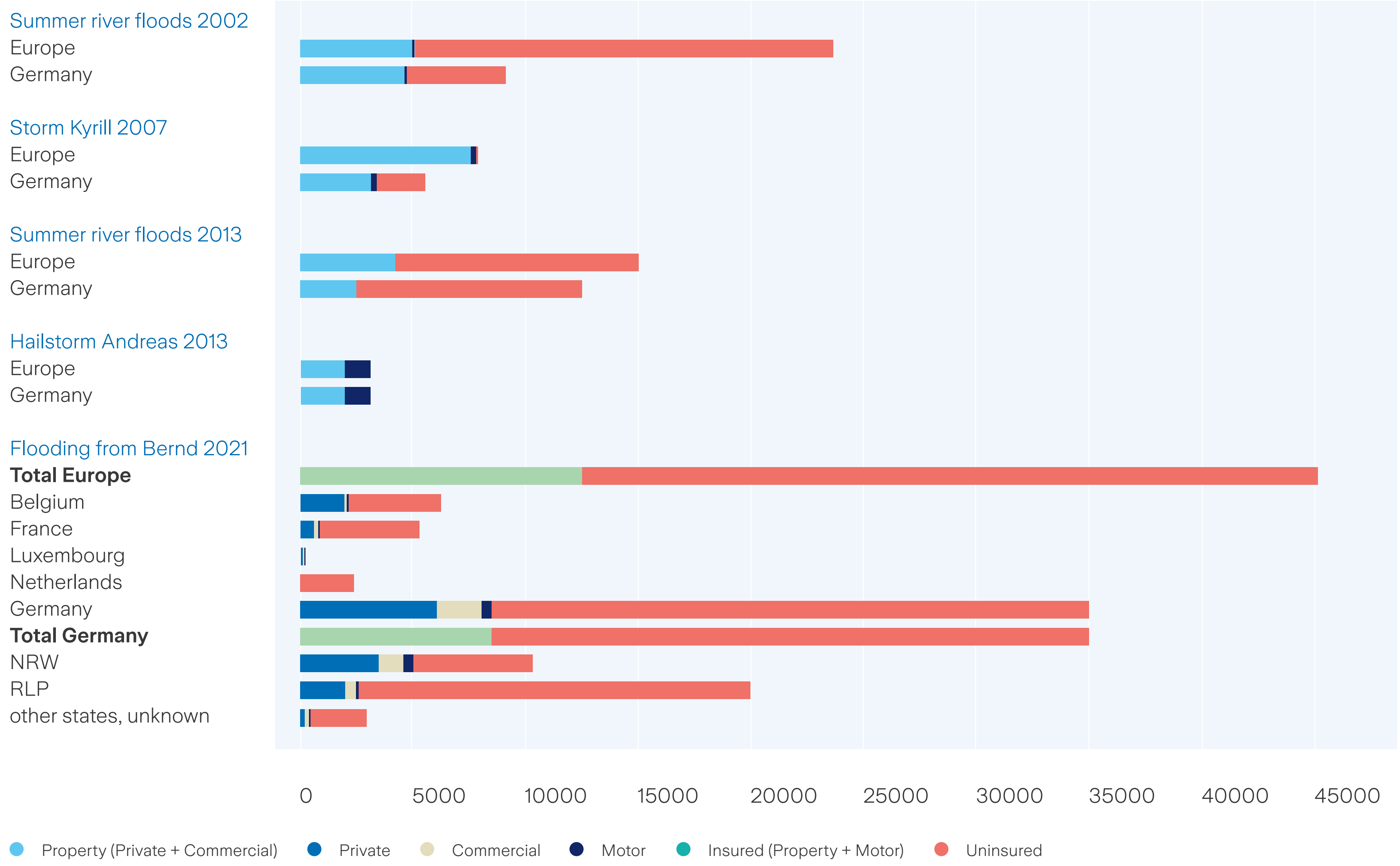
insurance would offer elemental cover as standard. The GDV position paper would require a quid-pro-quo from the state government to improve large-scale flood protection and ensure more restrictions are put upon exceptions to put new construction in flood zones. A GDV statement says that a five-digit number of properties have been built in flood zones in the Ahr valley in recent years. If there is not a stop to adding exposure to hazard zones, then losses will continue to increase. The insurance industry – not just in Germany, but in many countries – is asking for no-build-zones and for strict flood protection requirements both in space and at the individual level, and is asking for improving the flood statistics to better incorporate historic, large events as many time series of gauge measurements are too short.

As indicated before, “Bernd” was the most expensive natural hazard event for Germany, with expected total economic losses in the area of EUR 30-40 billion. “Bernd” was also reported as the largest insurance industry loss for 2021, with recent estimates of insured losses by the market to be about EUR 8.2 billion. What is notable is how the loss trends evolved as a function of time after the floods took place. GDV originally estimated that for their country coverage, the insured loss would be approx. EUR 5.7 billion but increased this later to EUR 8.2 billion as the extent of claims became clearer. At a global level, modelers likewise saw how market loss estimates moved continuously upwards based on increasing loss estimates from the direct insurers that then percolated through to increased loss reserves by the reinsurers, to then the market overview.

Reasons for the underestimation of losses stem from both a lack of understanding of this particular type of event, which was neither a pluvial flood nor a typical river flood, but somehow a combination of both, which may not be covered well by available flood models. Three points can highlight where the underestimation comes from:
First, the flood extent was underestimated. Reasons are to be found in the short gauge record and the limited flood statistics. Some modelers afterwards tried to run their models based only on the precipitation, and not the flood statistics, which got them closer to the actual flood footprint, whereas more conventional models using a traditional approach fell short of identifying the flood extent – this was relatively easy to correct as the flood extent became known ex-post: The widening of the affected zone then got the number of potential claims cases to the right level, which brought the loss estimate up.
A second underestimation comes from the claims experience - many seemed to assume loss severities based on their past flood history, which was mostly from the big rivers (Rhine, Danube, Elbe, etc.). But these floods cause different damage patterns. A good part of the insurance loss (under)estimation is because organizations used an average loss from prior (big river) flood events and applied it to the situation from “Bernd”. Additionally, many total losses became visible only at a very late stage, when buildings – sometimes already in refurbishment – still had to be condemned because of oil contamination.
The third explanation lies in the market conditions for building material and contractors, and the corresponding increase in cost.

Event losses are spread across around 250’000 claims made (up from an earlier GDV estimate of 190’000), most of which are located in NWR and RLP. The state directorate of RLP estimates the losses in their state to be up to EUR 20 billion, of which ¾ are uninsured. Of the insured losses, they are split between property (EUR 7.7 billion) and motor (EUR 0.45 billion) insurance. The focus of these insured losses is in two districts – Ahrweiler and Euskirchen, which make up more than 50% of total losses.
The Ahrweiler district also stands out significantly with the amount of the average private property loss – about EUR 210’000. Typical average flood losses are almost one magnitude smaller (GDV Management Bericht Q1/2022, GDV Natural Hazard Report 2021).

Insured Losses Graph – adapted from GDV and RMS
in million Euros, 2022



Insured and total economic losses of select natural hazard events in Europe in the last 20 years. Values indicate losses adjusted to 2021 prices and are based on the following sources: GDV 2021 losses estimated based on a GDV data call for "Bernd" and the GDV Risk Statistics 2021 publication. Loss data will be continuously updated and published by GDV; RMS Cat Summary 2021 and country split estimates – courtesy of RMS; Swiss Re Sigma Explorer data; national government data publicly accessible.

Operationally, the failure of critical infrastructure also impacted claims handling. How can customers reach out and place their claim? How can insurance get a good, rapid overview of the extent of the damage? How can insurance inspectors reach the affected locations? Given the huge extent of the event, everything was scarce, in particular the availability of independent assessors and contractors for the immediate drying of the buildings. Increased cost of working turned into a big problem and required and still require patience and understanding both on the customer's and the insurer's side. Due to the market conditions, prices were already up and the additional increased cost in an area of high demand post-disaster added to high price levels. But not every contractor offer can be accepted if it is multiple times higher than the usual price. We heard that insurers accepted price increases up to 25% and in some cases for some jobs even up to 40-50% higher, but very unreasonable offers by contractors in the area of 4-5 times the normal price were not unheard of. Here, insurance also has a duty to support and protect the customer, especially when they want to assign some contractor work up front.

Reconstruction and Learning

Reconstruction

Initially, some basic requirements and infrastructure need to be repaired before wide-ranging reconstruction is possible. This includes temporary road access such as ad-hoc bridges built by the military and the THW, some form of power and communication like mobile installations, and seemingly simple things like clean enough air to start working. The amount of dirt and flooded debris and the destroyed contents and equipment deposited on the side of the streets during extended days of summer heat and dry spells initially caused an unbearable amount of dust was around that got suspended in the air every time a truck moved by.

Luckily, some of this work was surprisingly fast and successful (as described in this Energy Agency RLP report). Despite so much critical infrastructure including electricity and power / gas / heating affected in a wide area especially in the Ahr valley, reconstruction was fast, due to a massive effort put in. The state government's crisis team charged the Energy Agency RLP to coordinate the heating requirements in the flooded areas. Despite the wide-ranging damage and the complex infrastructure losses besides the losses of heating plants in the individual properties, almost all affected people had at least temporary heating back for the winter following the flood, which was thought hardly possible when they initially saw the size of the task, but it was done. Relocating some of the transmissions, in particular gas to a better location, was done successfully and in short time – it seems that for energy infrastructure there are only few players involved which makes the planning and approval process much swifter compared to private or communal buildings reconstruction.

In a disaster of this scale and complexity, timelines start to blur. This is the case for transitioning from a chaos into a more organized response phase, for transitioning into a wider recovery phase, but it is certainly and mostly true for reconstruction, where people attempt to get back their "normal lives". Timelines also blur in this reconstruction phase because of the different actors and different interests. It is here where agreeing on a vision or plan, detailing the planning process and executing the reconstruction becomes really difficult. What we found missing was a visual, functional and protection-level coherence.

First of all, the scale of reconstruction effort needed far outpaces local capacity, especially in those communal structures in Germany that are heavily dependent on volunteers for official mandates, such as the mayors of smaller communities. There were significant complaints from the affected population that the public administration was working too slowly, but this is explained by the fact that within these often volunteer-based structures, the demands from the population meet an already stretched municipal and district administration (e.g. planning department) even in regular times due to a lack of qualified staff, financial resources and more and more and increasingly complex regulations and requirements.
The additional (financial) resources to manage the reconstruction are not enough and even if the funds are there, the market for qualified staff has been empty for years already (demographic change).

In many cases, the local administration structures were affected by the floods themselves and needed to get organized, which also took time. Then, it needed to be decided whether special structures would be created to manage the reconstruction process, or whether this would be integrated into existing administrational processes.

In Bad Neuenahr-Ahrweiler, a construction company ("Aufbau- und Entwicklungsgesellschaft") with 25 employees was created. This was done because the regular city administration structures could not cope with the demand for the reconstruction. They operate under the assumption that 100% of their 1400 individual projects will be covered by the reconstruction fund. However, the city has to advance some of the payments, in particular it remains unclear who will pay for the planning work. 80% of the city were affected.

A particular interest is where the future flood zone will be and how it will be determined, particularly at critical points like the outer curves of the river where destruction was particularly high, or at narrow points like the train station at Heimersheim. The latter previously held the river, the train rail, and four lanes of national road but during the flood held just the river. Similarly, questions about where to locate public infrastructure, parks, bike paths, and also gas and water lines all need to be resolved, but require a large cast of actors include the federal government and German Railway (Deutsche Bahn).

In Altenahr, 700 projects for reconstruction have been identified, totaling roughly EUR 1.4 billion – an enormous task that cannot be handled by the regular community employees. The community had only roughly half the employees that were needed and the while recruitment process has started, it is difficult to get qualified employees since other employers pay more, and on offer here is a difficult community job that does not look as attractive.

Getting back to the timelines, there is a difference between the communal and regional "public good" and public infrastructure, which is covered by e.g. an "Aufbaugesellschaft" and follows a communal administration process, and the reconstruction of the private and commercial properties, which follows another process and which work on completely different timelines and also different funding and compensation rules. Since these processes are so different, there is little overlap and hence little communication between the actors from the different processes, and they don't align with each other – not just with regards to the timing, but also the desired outcomes, such as creating a nice, visibly appealing and well protected city or town. This gap seemingly cannot be bridged, since the particular interests are so different. An individual homeowner wants to be back in their homes as quickly as possible, a commercial investor wants to maximize their effort and hence build the maximum that's allowed, while the community authorities try to provide the necessary decision-making and advice that's expected from them.

There are no known flagship or exemplary projects that document that a well-coordinated, coherent reconstruction from different actors could be done, e.g. a row of single family homes next to a public school that

coordinate their rebuilding approach, so that they function within an overall, comprehensive, visionary plan in which included there is a clear flood protection concept. This reality contrasts strongly with visionary statements made early after the flood that the reconstruction of the Ahr valley should lead to a model region comprising of lighthouse projects.
In practice, there currently is very little coordinated vision. For example, at communal or district level, there should be a coordinated attempt to rebuild the destroyed bridges, based on a clear flood protection concept that outlines the minimum height as well as the construction design to avoid repeat blocking with debris, a vision what architectural design these bridges should have, potentially a modern interpretation of the stone arch bridges for which big parts of the valley were famously known, and then get all the different owners or stakeholders for these bridges together – the community for communal bridges, the district for larger bridges, the state and national road authorities as well as Deutsche Bahn for the railroad. In reality, the locals fear they'll get an ugly mix of easy-to-construct steel and concrete bridges with no architectural concept at all, because there are no such visionary plans and/or rebuilding the bridges to the old look and feel, as apparently requested by the German foundation for the protection of historic monuments. Even the planning itself is difficult to achieve, since the planning budget comes from a different funding / subsidy mechanism than the reconstruction fund and is capped at a too low EUR 15'000 per community.

Reconstructing towards the new flood levels

The question of flood protection and required design standards for the future was asked very early, then discussed intensely, and it is a key pillar of the entire reconstruction debate. There were a lot of diverging political statements and promises made, ranging from the need to critically review where it is permissible to build and ensuring more room is left for rivers to avoid such damage in future (meaning that riverfront houses should not be rebuilt), all the way to a focus on the speed of reconstruction and getting as many people into their original homes as quickly as possible (with no consideration how to lower future flood risk).

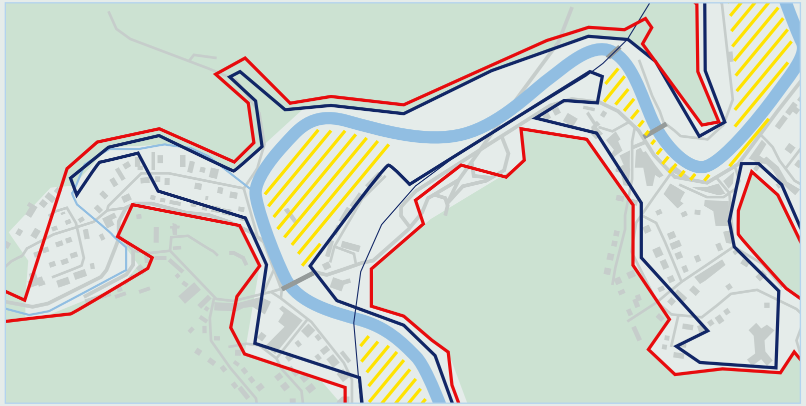
From a flood hazard and risk perspective, it was clear that the 2021 floods had an influence on the existing flood statistics, which as indicated had been based on a relatively short data record and did not incorporate the historic floods of 1804 and 1910. This is why the authorities decided to review and revise the statistics and correspondingly the flood zones ("ÜSG"). This usually takes many months, time the Ahr valley did not have as those waiting to rebuild needed clarity. The responsible "structural and licensing directorate North" (Struktur- und Genehmigungsdirektion, SGD Nord) used the legal option of a "preliminary delineation" based on initial new flood modeling to outline the new ÜSGs. This was presented to the Ahr valley communities in the second future conference for the reconstruction of the Ahr valley ("Wiederaufbau Ahrtal") on Sept 30, 2021.

These preliminary maps are showing three zones

Red zone: Extent of the extreme flood of July 14-15, 2021.

Yellow zone: within the ÜSG as a preliminary special hazard zone, where an exemption from the reconstruction ban for totally destroyed or statically damaged buildings cannot be usually obtained. This does not include only partially damaged buildings that can be reconstructed, as the grandfathering rule pertains to them ("Bestandsschutz"), these do not fall into the ban.

In the larger, **blue zone**, the rule is that reconstruction can be permitted, potentially observing requirements for flood protection. Again, grandfathered buildings do not fall under this rule.
It has been reported that many people are requesting these exemptions so they are allowed to rebuild – per limited available data to date, only 34 of 700 damaged properties may not be rebuilt, but in the meantime this number may be higher as contamination and mold have led to discovery of further total losses, which means grandfathering no longer applies.



For city and community planners we were told that this was very dissatisfying, these were too many exemptions. What has not been thought through and needs to be assessed – what happens with all those that are allowed to reconstruct in the blue / yellow zone or even have to because they don't fulfill the requirements to rebuild somewhere else - will they get insurance, and how so? If not, you're locking people into a problem when the next flood comes – who compensates them then.
This has been taken up with GDV and we are told that such properties will be provided coverage and at reasonable, risk-adequate but affordable premiums, potentially with significantly higher deductibles and prevention requirements according to Article 5 German Water Law. GDV believes the reconstruction planning is insufficient and the next disaster is already locked in through the current planning approach; especially since the 1804 flood event has not been considered in the delineation of the flood zones. Similarly, the question is whether a solidarity fund would bail out flood victim in future again – the rules currently require strict adherence to obligations when building in the flood zone; so if this is violated now or interpreted differently in future, another compensation may be difficult to justify.

In the blue zone, you can reconstruct, but you need to follow flood risk reduction measures, they must be implemented. Where that's impossible it may be that you can't rebuild there, either. Additionally there's the reconstruction fund rules by the ISB. Under certain circumstances, it is permitted to rebuild elsewhere, of course especially when located in the ÜSG and fully damaged, but alternatively as a rule created later, if the risk to life is assessed as elevated in the blue zone, and the damage, despite not a total loss, is significant, you may also get funding to reconstruct in another location even if there would be grandfathering – so two axes looking at extent of risk and damage to provide a more nuanced decision to allow rebuilding elsewhere. Yet, the same process and timelines apply to those situations as well, in particular the currently imposed application deadline of end of June 2023 to obtain reconstruction funding.
This deadline conflicts with many steps needed to get reconstruction funding: To understand whether one can rebuild, a building assessment

needs to be conducted but assessors are very scarce, those that can't reconstruct and need to find alternatives need to provide evidence they have access to new land on which to reconstruct, which simply is not available and takes time to identify and acquire. The deadline also adds to the problem of demand surge with contractors and correspondingly to increases in cost. What was found helpful were the various "info point" containers put in place in strategic locations by the ISB, where questions could be asked and support to fill in the application forms be sought. At this point it remains unclear whether the deadline will be extended or not by the government – it also applies to the communal funding applications, and for them it is particularly difficult to complete all the planning and hand in the application.

At city level, in Bad Neuenahr-Ahrweiler they are continuously considering changing construction rules so that roof spaces over a certain minimum area and depending on their slope need to be greened; front and back yards and driveways cannot be sealed/paved over but must infiltrate water, and to ensure the city on their public spaces can act as a role model and as a city avoid sealing new surfaces and potentially even open up old, sealed space to increase infiltration. While small steps, these will provide benefits in all circumstances and can be called no-regret solutions. They will not solve the problem of extreme floods in the Ahr valley, but are an important steppingstone to reduce smaller floods, potentially below damage levels.

Building back better or building forward

Though critical infrastructure was re-established surprisingly swiftly as explained above, what was not as successful was the transfer to more sustainable solutions including the switch to district heating and replacing oil heating. While often, intent was declared to turn the Ahr valley into a model region, to build a concept for a climate neutral Ahr valley and to create an "innovation and development society" for the Ahr valley, these remained keywords[10]. No formal structures including in existing law were put in place to allow this to happen. The timelines for such approaches are at odds with the required speed for reconstruction, and the different funding pots make applications and a transparent understanding about what's possible and what's not very difficult as soon as it goes beyond building just back to as was. To come up with a master plan and align the different, often competing interests, one would really need to stop everything in the disaster zone, take 2-3 years' time to complete coherent planning, and only then come back and start rebuilding – which in practice is an illusion, of course.

The energy agency RLP has tried to support this switch by providing a guideline on how to incorporate more sustainable heating into the reconstruction, but it becomes clear that too many different entities for advice, approval and funding are involved and that funding streams for the reconstruction and for the funding of new energy sources run separately[11]. The reconstruction entities have received a clear mandate from those that organized the reconstruction process to solely focus on reconstruction and not on betterment. They feel these processes need to be kept separate, which creates an additional hurdle for citizens to grasp the opportunity of reconstruction to make their building fitter for the future. An individual community (especially an association of municipalities) cannot achieve building back better and providing the support to citizens alone. This requires a master plan, a vision, a coordination at least at the district level, which was not put in practice. A concrete translation of the keyword of an energy vision into a measurable objective, "By 2035, the Ahr valley will be…" with specific pathways how the flood reconstruction process will act as an opportunity to achieve this. To achieve this what's needed is an expedited planning phase, clarity from the outset what will be achieved as a minimum standard, even if the authorities don't know quite yet how this will be done - they need to provide confidence and reassurance. Like other aspects of the reconstruction, this probably can only work if it is pre-planned before a flood disaster. Otherwise the timelines are so different and permission processes and construction laws are so rigid that change cannot take place - a serious problem. After the intentions were declared but could not be easily put into practice, the enthusiasm and speed stalled. The population was left with the impression that this might take years or never come, and then decisions are taken by customers, by the individuals, to put back another gas or oil heating, to not upgrade, to just build back. Energy companies and organizations did not have a sustainability plan to jump to the opportunity to do something transformative and support the affected population with new sustainables, either. They did not use the opportunity to help customers switch, at scale, to geothermal, solar, or heat pumps. What was seen instead was an opportunistic approach to immediately deliver gas and oil heating to gain a short-term competitive advantage.
At a larger scale, building forward the valley and implementing flood protection measures has its limitations given the size and topography of the valley with many tributary creeks that are hydrologically not well monitored or understood. They all contribute to the flooding problem in the valley, also since the villages on top of the hills have recently grown and more area has been paved over, increasing the runoff directly into these tributaries. While space up in the hill might be available for retention basins, their use may be limited and they would need to be so numerous that both from a grey infrastructure as well as from a cost perspective this might be prohibitive. Keeping the upper, more natural part of the Ahr valley floor free to let flood waters flow naturally and slow the speed of the flood wave is one solution which also brings benefits from an ecological and tourism perspective. The opposite, constructing a big dam like in many rivers in NRW, might neither be desirable nor feasible. Ultimately, the idea of a flood bypass tunnel in the middle valley that would help the narrower parts of the middle and then the lower valley with its denser population has been floated. This would take excess water that the lower part of the river cannot handle directly to the Rhine – quite a massive undertaking.

10 e.g. Minister Spiegel, https://hochwasser-ahr.rlp.de/de/presse/pressemeldungen/detail/news/News/detail/spiegel-aus-der-schrecklichen-hochwasserkatastrophe-muessen-konkrete-schluesse-fuer-die-zukunft-gezog-1/

11 https://www.energieagentur.rlp.de/fileadmin/user_upload/bauen_und_sanieren/Schritt_fuer_Schritt_zum_nachhaltigen_Wiederaufbau_in_Flutgebieten.pdf

While not unheard of, the feasibility is questionable but it seems that a feasibility study, although requested, has not been conducted.
One major challenge that the project team have heard almost as consistently as the disbelief that a disaster of this magnitude could strike was the attempt or the vision of the authorities to be "unbureaucratic", approachable and supportive, where in reality many if not all processes were felt to be complicated, untransparent and very bureaucratic, including the application and approval process for the compensation fund by the ISB, the requirements to obtain reconstruction approval and/or exemptions in the flood zone, the approval to start planning processes at the communal level for services and infrastructure including the reconstruction of roads and bridges, and many more. On the other hand, the law needs to be respected and there is a trade-off between approving applications and paying out fund money too easily, and taking too much time to check the applications in-depth. One problem might also be that while the administrational and financial competency for the application and payout process is certainly there, resources are scarcer to provide technical advice and support, which is not the competency of the ISB but may need to be sought elsewhere.

As a bottom line, we see that coordinating action and taking decisions become difficult and timelines are impossible to align when reconstruction is planned only after an event, when rules and structures for flood re-zoning, reconstruction of private and public infrastructure and the corresponding funding applications have to be put in place after a flood disaster, and many additional explanations and regulations added in later iterations because they originally had been overlooked as the authorities were balancing between speed (providing fast solutions to the flood victims), and accuracy (to consider all the eventualities). A reconstruction process could be done so much better if it was all pre-planned based on a joint vision, before a disaster, including how and where you do reconstruction after a big disaster.

> We always hear unbureaucratic, I believe this wins the "worst word of the year" award here in the Ahr valley, as all processes are totally bureaucratic
>
> resident in the Ahr valley who lost the home she grew up in

Learning from the event

First of all, we are grateful to know that learning from disaster events has been declared very important by a variety of actors involved in the "Bernd" floods. In fact, such learning is a requirement in the Sendai Framework for Disaster Risk Reduction in Priority 1, Article 24g and in particular 25g ("use post-disaster reviews as opportunities to enhance learning and public policy; and disseminate studies") and in Priority 4, Article 33j (***"sharing of expertise, knowledge, post-disaster reviews and lessons learned and integrate post-disaster reconstruction into the economic and social sustainable development of affected areas"***) which we use as the basis for our PERCs[12] . Learning from disasters is immensely important to draw lessons from what has happened and pave the way for urgently needed improvements.

We also noted that several bodies have formed and research has been commissioned to provide learning. Of particular note is the criminal investigation on "the initial suspicion of negligent homicide and negligent bodily harm as a result of possibly omitted or delayed warnings or evacuations of the population in the Ahrweiler district", the two parliamentary inquiry bodies in RLP and NRW, as well as a more technical "Enquête Commission" in RLP. Besides, there are a suite of research projects, e.g. "KAHR"[13]. While trying to learn is always positive and of course if criminal negligence has taken place this must be pursued by law, our PERC team has observed as well as heard from interviews that the tone and approach of these investigations have become an obstacle in neutrally and objectively evaluating the disaster. People are afraid to speak up, are delaying information or omitting critical information in the fear of highlighting something that otherwise would not have surfaced,

12 https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
13 https://www.fona.de/de/massnahmen/foerdermassnahmen/KAHR.php

irrespective of whether it might or might not be relevant for the respective investigations. We also note that the parliamentary inquiries have components of political aspects that don't necessarily provide learning unless a stronger mandate for such learning is provided, and tend to take an approach of trying to cast blame instead. They also have turned into a big effort for preparations, with allegedly close to half a million pages of paper being handled without an attempt to draw conclusions for future improvements. People wish that the various bodies would move closer together and really look at learning and how institutions could work together better, both across functions working along the disaster risk management cycle as well across the vertical layers (see our institutional landscape infographic earlier).

Before reconstruction takes place, it would be good to pause and have an honest discussion and transparent decision-making process how the reconstruction should be done and implement elements of transformation and imagination. Local authorities felt decisions were imposed on them and that these decisions had been taken without asking frank questions. In the narrows of the Ahr valley, is it really desirable to build back the railway tracks when the river so urgently needs more width? Is it really good timing to start reconstruction without an overarching flood protection concept established yet? And where can we use opportunities created by the flood to make room for the river and implement changes rather than put the river course back to where it was? And is it good practice, despite legally allowed, to go ahead with a new construction project in the flood zone that had just been approved prior to the flood disaster? There are already too many buildings in the flood zone and essentially everybody is aware of this and acknowledges the fact, but somehow the political or socioeconomic lessons to change the underlying framework that permits this are not learnt, despite precedence from earlier floods in the same country, only in another state – the example of the industrial zone of South Röderau at the Elbe comes to mind, consciously built into a flood zone.

Section IV: What happened in Belgium

In Belgium, very heavy rainfall associated with cut-off low-pressure system “Bernd” led to severe flooding over the period July 12- 15 period in the south and east of Belgium. Rains began Monday July 12 and intensified Tuesday July 13, causing several rivers and streams to leave their beds, particularly in Walloon Brabant, the Charleroi region and the provinces of Namur and Liège. In the night of July 13 to 14, the situation worsened further in the province of Liège: the center of Spa and that of Theux were under water and in Méry the Ry de Gobry, a small creek on the right bank of the Ourthe and a sub-tributary of the Meuse, transformed into a torrent that carried away vehicles. As the day progressed on Wednesday July 14, the floodwaters moved into the towns of Jalhay, Ferrières, Raeren, Trooz, Chaudfontaine, Grivegnée, Angleur and Esneux, several national roads were cut, and many more towns and villages were watching as the rivers and creeks crossing through them swelled. Further northwest, in the province of Hainaut, floods struck Aiseau-Presles, Acoz, Bouffioulx, Charleroi, Châtelet, Ham-sur-Heure, Marbaix-la-Tour, Braine-le-Comte, Couillet and Maurage.

In the evening of July 14, the governor of the province of Liège ordered the evacuation of eleven streets in the city of Limbourg as the river Vesdre was leaving its bed. However, the situation appeared to stabilize elsewhere along the Vesdre and many thought the end-of-day lull marked the end of the flood. This was not to be; torrential rains picked up again in the evening. In the small hours on Thursday July 15, around 3 or 4 am, the Vesdre, the Ourthe and the Meuse burst their banks and flooded a large part of the towns they crossed: Verviers, Pepinster (also flooded by the Hoëgne), Eupen, Dolhain and other communities along the Vesdre (Nessonvaux, Fraipont, Trooz, Chaudfontaine, Vaux-sous-Chèvremont), and two neighborhoods in the city of Liège (Chênée and Angleur).
The towns of Pepinster and Vervierswere hit particularly hard. They found themselves engulfed by floodwaters reaching up as high as the second floor, withwater rushing through town streets several hundred meters from the rivers, trapping hundreds of people in their homes. In Pepinster at least 20 houses collapsed along the straightened riverbed of the Vesdre and 23 of the 31 casualties as of July 18 were found here. In Verviers, more than 10’000 of its residents had to be moved because homes had become uninhabitable. Looting also became a problem, resulting in a curfew in Verviers in the nights of July 15 and 16.
As the flooding progressed, several communities along swelling rivers shifted towards a more cautious approach. On Thursday, July 15 all residents along the rivers Meuse and Ourthe in the city of Liège were urged to evacuate amidst fears that the Meuse and Ourthe were on the verge of bursting its banks and that a dam bridge could collapse. Similarly, the governor of the province of Namur recommended residents to stay at home and upstairs, if possible, while the governor of the province of Walloon Brabant triggered the provincial emergency plan due to floods and mudslides in several municipalities in the province, in particular in Mont-Saint- Guibert, Chastre, Walhain, Jodoigne, Grez-Doiceau, Chaumont-Gistoux, Court-Saint-Étienne, Villers-la-Ville, Ottignies-LLN, Genappe and Beauvechain. By Friday 16 July, several smaller municipalities (Smeermaas and Herbricht) in Limburg Province were also given the order to evacuate and several tunnels in the capital Brussels had to be closed due to floods, and several provinces in Flanders (Limburg, Antwerp and Flemish Brabant) also reported flooding.

As of July 28, 2021, the Walloon Government recognized the floods brought about by “Bernd” as a public disaster and listed a total of 202 municipalities as affected, including all 84 municipalities of the province of Liège, all 38 municipalities of the province of Namur, all 44 municipalities of the province of Luxembourg, and several municipalities in Walloon Brabant and Hainaut. 7 more communities were added by the Walloon government on August 26. The municipalities where the flood impacts and needs on the ground were greatest were Chaudfontaine, Esneux, Eupen, Liège, Limbourg, Pepinster, Rochefort, Theux, Trooz and Verviers.

Across Wallonia, more than 41’000 households were without electricity at the peak of the event and more than 3’600 people were cut off from the gas network in the Liège region. This was the result of both damaged and deliberately switched off electrical cabinets to prevent serious damage. It took around three weeks to fully restore power. Similarly, potable water became a scarce resource in several municipalities in the affected provinces, as turbid water resulted in tap water that couldn’t be used for food purposes, even if boiled. It took months to restore the gas distribution to a close-to-normal condition. At the end of December 2021, gas was still unavailable in some parts of affected municipalities. Mobility was severely disrupted in all Walloon provinces with dozens of road sections closed to traffic due to flooding, trains almost at a full standstill and bus lines across several provinces disrupted. The province of Liège was particularly impacted with the centers of Spa and Theux inaccessible for some time.

Overall, the summer 2021 floods are considered the most devastating in Belgium’s history. Preliminary estimates of the cost of insurance claims suggest these are exceeding EUR 350 million, overwhelming insurance companies across the country. The damage to the railroad infrastructure alone are estimated at more than EUR 50 million, while the region is faced with long-term reconstruction bills as they address colossal damage to public infrastructure, currently estimated at EUR 650 million. The damage estimates break down to EUR 23.8 for the road network, EUR 19 million for bridges (33 bridges are subject to partial or complete traffic restrictions), EUR 55 million for the rehabilitation of the E40-E25/Cointe tunnel link (lighting, ventilation, remote management, emergency exits, video surveillance, etc.), EUR 36 million for the waterway network (130 sites impacted including the repair of walls and banks on around fifty sites) and EUR 22.5 million for the rehabilitation of 343 storm basins. In addition, the Walloon Government has issued EUR 2 billion through various recovery and reconstruction budgets. Donations were high in Belgium, too: One month after the flooding, the Belgian Red Cross had received EUR 35 million in donations, a record sum for the organization.

Photo: Many houses nestled along the Vesdre in Verviers, Belgium, were destroyed during the summer 2021 floods. Teresa Deubelli, IIASA.

Preparedness

In Belgium, like in other EU member countries, flood risk management is guided by the European Union (EU) Directive 2007/60/EC ("EU Floods Directive") that Belgium has fully put into practice as of 2013.
The responsibilities for implementing the Water Framework Directive in Belgium are divided between the Federal State, who handle coastal waters, and the 3 Regions (Flanders, Wallonia and Brussels-Capital Region), who handle rivers, lakes, transitional waters and groundwater. The Flemish River Basin Management Plans were adopted in 2010 and those for the Brussels Region in 2012. In Wallonia, River Basin Management Plans (PGRI) for the rivers Scheldt (Escaut), Meuse, Rhine (Rhin) and Seine were adopted in 2013 and updated in 2016[14] and most recently in 2022[15]. These plans encompass all aspects of flood risk management from prevention to post-crisis analysis and include global objectives applied to the entire Walloon Region, resulting from the prior P.LU.I.E.S. Plan[16], as well as specific objectives and measures for each sub-basin.

To prepare for floods, Belgium relies on publicly available flood hazard maps that illustrate both areas possibly subject to river flooding, but also runoff flood and mudslide hazards, as well as rainwater runoff information. In Wallonia, flood hazard maps are updated every 6 years, with the latest updates dating back to 2020 when they were submitted to a public inquiry (September 14 to October 31, 2020) and approval by the Walloon Government on March 18, 2021. In Wallonia, mayors need to consider the flood hazard maps in their urban planning decisions (approximately 10% of permit applications are concerned by problems of exposure to flood risks), and flood preparedness measures are taken in view of the available flood hazard maps. However, as was seen in the summer 2021 floods, the red zones illustrated in the maps more or less equate to the riverbed of the Vesdre, with neighboring areas marked orange, yellow or green (or no color). As a result, many residents reported surprise at their houses facing flooding up to their second floors, seeing how they had understood these not to be in flood areas. Similarly, several stakeholders interviewed during our visit to the region attested that they would not expect another flood of this level, seeing as how the floods were a 100-year event, illustrating a need to better translate the technical information about return periods and flood zones into actionable information for local decision-makers and residents alike.

In terms of units prepared for responding to floods, Belgium relies on its federal civil protection and the local emergency services like fire brigades, first responders and the police, with the army stepping up in case of extreme disaster. Following reforms in 2019, the Belgian civil protection system experienced substantial cuts, with only two civil protection central units out of the existing six maintained - Brasschaat (province of Antwerp) and Crisnée (province of Liège) – and an operational center in the capital, Brussels. Before the reform, the Crisnée Civil protection unit encompassed 266 professionals and 379 volunteers. As of January 2020, only 139 professionals remained (i.e. a reduction of 127 people) and 129 volunteers (a reduction of 250). As a result of the reduced civil protection capacities, several of the emergency services interviewed as part of the PERC noted that given the scale of the disaster, neither the army nor the civil protection had the necessary equipment nearby to respond to the floods, even though they are the units to call upon when a disaster exceeds local capacities or requires specialized means. Given the location of the two remaining units in Brasschaat and Crisnée, parts of the country are also cut off from rapidly deployable units, relying on the cooperation of local emergency services instead (for example, the Ghent fire brigades took initiative to provide rescue boats in support of rescue operations in affected areas).

14 https://inondations.wallonie.be/home/directive-inondation/plans-de-gestion-des-risques-dinondation/pgri-2016-2021.html
15 https://inondations.wallonie.be/home/directive-inondation/plans-de-gestion-des-risques-dinondation/pgri-2022-2027.html
16 https://inondations.wallonie.be/home/directive-inondation/historique---plan-pluies.html

Forecasting/Early Warning

The European Flood Awareness System (EFAS) noted the need for "preparatory measures before major flood events" to be taken up along the Rhine, in particular the portion running along the border with Germany, and the Meuse in eastern Belgium and the Netherlands on the weekend prior to the events. As of Monday July 12, the RMI had observed that weather models were predicting extreme amounts of precipitation, with 100 – 150 mm expected in some areas and forecasts crossing the pre-alert and alert levels in the night from Tuesday to Wednesday. The Flemish Environment Agency (VMM) observed on Sunday July 11, that its forecast system was detecting severe floods for the upcoming week. On Monday July 12, VMM started to warn and pre-alert the civil services, the governors of the provinces and the responsible services for the different water courses. On Tuesday July 13, VMM published a flood alert for the Eastern part of Flanders. Although these observations were passed on to the relevant regional counterparts, the Walloon officials in charge of watercourses (SPW MI), there was no pre-alert or published alert until Wednesday July 14, almost two days later. The RMI's alert deadlines further complicated the issuance of timely alerts: A yellow alert can be issued 48 hours before the event, an orange alert 24 hours before the event and a red alert 12 hours before the event. It was therefore necessary to wait until 14 July for a red alert to be issued, even after significant rainfall had been forecast.

When the alerts were finally triggered at 6 am on July 14, several towns had already been flooded, while others struggled to cope with the extreme intensity of the predicted floods: the heavy rains exceeded the predicted rainfall by 50% and previous highest measurements by 100%. And, even when the alerts were finally triggered, not all communities translated them to evacuation orders; only the city of Limbourg issued evacuation orders late on July 14 as the river Vesdre was leaving its bed, while others followed suite the next day, July 15, as the flooding had already devastated several communities.

The delays in triggering alerts and challenges in interpreting them into evacuation orders on the first days of the flood were linked to a number of constraints:

- In Wallonia, the announcement, monitoring and forecasting of floods is the responsibility of the manager of the waterways of the Public Service of Wallonia Mobility and Infrastructures (SPW MI) and more specifically to the Directorate of Hydrological Management (DGH). Warnings need to be issued by the corresponding regional authority and cannot be issued by RMI.
- To anticipate, determine the risks and trigger the alert phases, the duty operator has a series of hydrological models to predict the evolution of flows in the main Walloon basins. More than 35 models are deployed in Wallonia and are all based on stochastic modelling. These models compare real-time hydrological measurements and meteorological forecasts with previous floods in order to reproduce equivalent responses. However, these models concentrate on the larger, first order river basins. The second and third order rivers and creeks like the Vesdre and other (sub-)tributaries of the Meuse are not monitored with the same level of detail as the larger basins. As most of the flooding during "Bernd" occurred along these less well monitored basins, the available regional models did not illustrate the same level of urgency as those available at the federal and European levels.
- The Walloon forecasting services traditionally focus on maintaining hydrological models for assessment and planning purposes, including related to energy production and to verify the navigability of waterways and plan and control dredging. As a result, and due to the complex topography of the Ardennes, precipitation forecasts for Wallonia cannot be fully translated into likely flood footprints and potential impacts in real-time to inform early warnings.
- The meteorological models in use at federal, Walloon and Flemish levels differ. While the federal level draws meteorological forecasting information from up to five different models and cross-checks them with the models in neighboring countries, the regional services rely on fewer models and are thus more likely to miss early indications of extreme weather events. This capacity is further hampered by lack of coordination across the Belgian Flanders-Wallonia linguistic divide.
- The "Bernd" flooding took place during the summer months. Because flooding is typically a winter phenomenon the Perex center, created to centralize round-the-clock 24/7 monitoring services, was understaffed. The understaffing was noted to be due to vacation-related absences coupled with a general issue of understaffing the on-call services.
- Many local decision-makers, first responders and crisis managers reported difficulty understanding the messages and alerts they received – they were not adequately explicit or were too technical. For example, the meteorological services would report precipitation levels in 1 hour, 3 hours, 1 day or even 3 days windows. No one actually knew what that meant in terms of what impacts to expect on the ground.
- Similarly, when the decision was made to open the Barrage de Monsin dam to avoid flooding Liège with its near 200.000 residents, stakeholders we interviewed reported that they struggled to interpret the information they received. Rather than receiving information about how high the floodwaters might rise or where flooding might occur following the opening of the dam, they were told that the waters passing through the dam would increase from 43 m3/s to 90 m3/s – as some put it, they were faced with a mathematical problem rather than with actionable information.

In the absence of formal timely warnings, for many residents and first responders the flooding came as a sudden and devastating surprise. In many places, local police took things in their hands and warned residents in the affected areas of the imminent dangers. In the worst hit neighborhood of Pepinster, for example, officers waded through flood water to put up signs asking people to stay away from several houses still at risk of collapse. Other officers used the loudspeaker of their police van to spread public service announcement in the streets.

Response

Though legal frameworks are in place in Belgium to address localized crises or emergencies, many stakeholders reported that given the recent civil protection reforms and limited awareness of the risk of extreme flooding from heavy rainfall during the summertime, when many local decision-makers are on holidays, they relied on ad-hoc improvisation and pragmatism more than clear risk governance arrangements. For example, in Verviers local police improvised to set up a functioning crisis coordination room. The ad-hoc crisis room brought together representatives from the local fire brigades, paramedics, mayors (or vice-mayors, as some mayors were on vacation then) and police representatives and relied information provided by their teams in the field more so than on forecasting and early-warnings, which in many cases arrived after the floods had struck and often didn't reach the communities that were affected. As the communication networks broke down in some of the affected areas (particularly in the Liège and Verviers regions as well as in the municipalities of Eupen, Raeren, Rochefort, and Marche-en-Famenne), communication by radio message and speakers replaced other means of communication.

The city of Limbourg issued an evacuation notice late on July 14, and several additional municipalities in the provinces of Liège and Namur received evacuation notices July 15. However, for the most part first responders and local authorities both asserted that they would have needed more concrete indication of the expected impacts of events (water levels, flooded areas, etc.) to help them determine what measures to take on the ground. As a result, in some of the hardest hit areas, people were forced to self-rescue. In several of the most affected towns in the province of Liège people were trapped on roofs, often without food or drink for 36 hours, as the floods were too dangerous to navigate (so much so that in one case a rescue operation failed when a rescue boat capsized after a collision with debris, costing the lives of the three people to be rescued). Given the scale of the event, there was immediate recognition that outside help was needed. The first line of escalation in Wallonia would be to the Wallonia Regional Crisis Center (the CRC-W) that acts as a regional single point of contact for the authorities in charge of crisis planning and management (National Crisis Center, Governors, police zones, disciplines, municipalities) and informant for the Walloon Government. However, throughout our interviews we found that while the CRC-W has been operational since 2008, based on a decision of the Government of Wallonia, the CRC-W – like other crisis management actors - struggled to cope with the unprecedented scale of the floods. This was further hampered by several decision-makers out on vacation with no trained backup.

This meant the event was then escalated to the national level. The army was dispatched to affected areas to help with rescue and evacuation operation, spearheaded by local paramedics, police, and fire brigades. Similarly, calls for support from other regions of the country were issued: During the night from Wednesday to Thursday, a crew of firefighters from Antwerp left to assist the province of Liège, bringing much needed divers with boats as well as rescue equipment. The Brussels-Capital region sent personnel and equipment to the provinces of Liège, Luxembourg and Flemish Brabant from the firefighting and emergency medical assistance service. Brussels Prevention and Security provided drones to examine the extent of the damage and the municipal transport company of Brussels (STIB) provided heavy equipment, including trucks, cranes and buses to help transport people from the affected regions. Further aid, such as personnel and equipment (drivers, team of sweepers, generators, trucks, etc.) reached the region from municipalities in the region. As Belgian capacities persisted to be overwhelmed, Belgium activated the European Union's Civil Protection Mechanism to ask for international support. The Netherlands, France, Italy and Austria all sent support in the form of rescue teams, boats and helicopters. France has also sent 40 civil security rescuers and Austria sent a convoy of 103 firefighters as reinforcements to the province of Liège.

Several controversies arose about the management of dams during the floods. The dams of Eupen and La Gileppe (both are normally used as drinking water reservoirs and power stations), as well as the Île Monsin

Photo: Teresa Deubelli, IIASA

dam (which regulates the water level to ensure the circulation of boats), came close to their maximum storage capacity during the floods, with worries about them bursting. While they ultimately did not fail, local authorities made emergency releases from both the Île Monsin dam and Eupen dam. Failure of either of these dams would have been catastrophic for downstream communities; consequently, local and provincial authorities devoted significant attention to tracking and developing possible scenarios for action. Ultimately, it ended – mostly - well; an even larger disaster was avoided. However, particularly for the Eupen dam, earlier action might have resulted in less damage downstream. Residents of Chaudfontaine, which was flooded in the aftermath of the opening of the Eupen dam, suspect that delayed opening of the dam – possibly due to economic interests - contributed to the devastation brought upon their municipality by the floods; a judiciary investigation into this is pending.

Recovery

Shifting from the initial response phase to a more organized recovery phase posed a new set of challenges for the affected regions in Belgium with varied needs across the geographies and roads, bridges, and other essential infrastructure, such as electricity and gas networks as well as telecommunication services, were destroyed.

Starting in the early recovery phase, volunteers from Belgian humanitarian organizations such as Terre des Hommes, Christian Aid, Doctors Without Borders (MSF) and the Belgian Red Cross stepped up and offered support to the affected communities. Aid included support in picking up the pieces, salvaging what was salvageable and mucking out. The Red Cross launched an appeal for donations, supported by the Belgian National Lottery who released EUR 1 million to provide emergency aid to flood victims in the Meuse basin. To allocate donations in line with the needs of the victims the Red Cross developed an 8-month action plan, coordinated by a newly set-up flood response unit. This included targeted financial aid to the most vulnerable people: EUR 650 per household, increased by EUR 195 per person attached to the household. 6’584 households benefited from this aid and a total sum of EUR 6 million was distributed. However, as our interviews revealed, getting financial aid to the most affected households proved more complex than anticipated, as some victims were unaware of the available support, and there was no public overview of bank accounts to which to transfer support.

Donated funds also went to feeding and sheltering people, for direct material aid, to schools to help them clean up, restock and reopen, and for aid and psychosocial support. In addition, the Red Cross has organized long-term aid for 28’000 disaster victims until the end of 2024.
This highlights the particular challenges of extreme events in areas of high vulnerability. If those impacted are under or uninsured, out of work, elderly, disabled, or otherwise less able to rise to the challenge, support beyond just a few weeks or months is typically needed to get them stably reestablished and functioning without outside support.

To better channel the public support that streamed in in addition to the support through established non-governmental organizations, the SOS Floods platform (#aidehulp147) was set up. There, those who wish to support victims can list their services and items on offer or respond to specific requests for help or to volunteer to help on site. Many people donated clothes, toys and furniture for free. They also offered their help in cleaning up houses, transporting goods or taking care of animals.
Those wishing to respond to specific requests for help were also able to connect on Facebook, where several groups organized the volunteer efforts by region. Several local clubs, such as the Sporting d’Anderlecht, organized charity events to support the flood victims, and Doctors Without Borders (MSF) offered individual face-to-face sessions with a Doctors Without Borders psychologist for municipal authorities and emergency coordinators and collective emotional support sessions (talk group + information on stress) for volunteers, first-line responders and CPAS workers. The Adolescent Children’s Network in the province of Liège Mental Health (REALiSM) and the local health promotion centers (CLPS) of Huy-Waremme, Liège and Verviers organized videoconferences followed by a group discussion.

To inform victims about available support from the regional government, the Special Commission for Reconstruction (CSR) distributed an information brochure on housing aid and published a “Wallonie Inondations - Reconstruction” newspaper. A budget of at least EUR 25 million was earmarked for energy aid, in the short and medium term to enable disaster-stricken households (whether their accommodation is still habitable or whether they have been relocated) to spend the winter in safe conditions. As further support, the Walloon government granted a subsidy of EUR 1.5 million to the Regional Mobility Center (CRM) that foresaw free local public transport for the victims from the 209 affected Walloon municipalities (August 12 - October 31, 2021).

To ensure housing for affected households, the Walloon government issued EUR 27 million of support via the CPAS, distributed to the most affected municipalities who were charged with managing rehousing efforts. A further EUR 25 million was provided to the public service housing companies (SLSP) to rehouse tenants from affected social housing. In addition, the Walloon housing society launched a framework agreement for the rental of modular housing installed on serviced land (with access to water, electricity and heating). As of December 6, 2021 80 people have been relocated to Chaudfontaine via modular housing.
In Rochefort, 16 modular houses could be installed through a 1 million fund provided by the Belgian Red Cross.

Photo: Teresa Deubelli, IIASA

Insurance and public recovery funds

Although homeowners' insurance (assurance habitation) is not compulsory in Belgium, insurance providers are legally required to offer insurance to all households in the country. As a result, and as many mortgage providers and landlords ask for such insurance coverage to be taken out, around 95% of households in Belgium have a policy. Since 2005, cover for damage caused by flooding is obligatorily included in the household insurance package that also includes risks such as fire. Flood coverage is limited; however, a "flooding" component is only included if the property was built in a flood risk area less than 18 months after the date of publication in the Belgian Official Gazette of the royal decree classifying it as a flood risk area.

Consequently, insurance was the primary line of financial support for those affected by the floods. Insurance companies activated their "crisis procedures" to help people affected by the floods in the short term and called their staff into work from leave so that affected customers could receive assistance more quickly. Yet, in many cases local recovery efforts had already started by the time insurance experts arrived – at least mucking out and recovering salvageable assets -, complicating damage assessment and resulting in different views about the exact scale of damage. In some cases, advances on payouts were made possible once the initial assessment of the damage has been carried out, but in others insurance companies found themselves overwhelmed by the sheer size and number of pay-outs they were faced with, struggling to carry out payouts in a timely fashion, or at all.

On August 12, 2021, the Government of Wallonia announced that insurance claimants in the 209 municipalities subject to the "public disaster" recognition would be compensated for 100% of the damage estimated and covered by their insurance policy. As the payouts from insurers exceeded the available reserves by so much that affected citizens would have only received 19% of the amount of the incurred damage, the Walloon government initiated a support scheme for the insurance sector. As agreed with Assuralia (which represents the insurance sector), insurers would double their intervention ceiling (i.e. 38%) and the Walloon Region would bear the entire remaining balance via the newly-created Disaster Fund (based on a "disaster exception decree" which defines the specific conditions for compensation and is more generous than the compensation scheme of the Calamity Fund would normally be)). Based on current provisional estimates, insurers would thus provide EUR 613 million and the Walloon Region EUR 990 million as insurance pay-outs to insured flood victims[17].

For uninsured flood victims, the Government of Wallonia grants partial compensation (up to 50% of the damage assessed by an expert with a maximum ceiling set at EUR 80'000 or 90'000 EUR in case of depollution). This included support for movable properties located inside of damaged buildings, with a limit of EUR 10'000 per claimant. Additional support was made available for people within the social income scheme (RIS). The Walloon government has also set up an interest-free loan mechanism for self-employed and businesses affected by the floods, accessible via the public Walloon SMEs financing group (SOWALFIN). Uninsured companies and non-profit organizations were able to apply for coverage of up to 25% of the estimated damage, with a maximum intervention ceiling set at EUR 500'000. Farmers without insurance could apply for 70% reimbursements, while foresters were able to apply for 35% reimbursements. In both cases, the maximum payout ceiling was set at EUR 300'000.

The Government of Wallonia released emergency aid of EUR 2.5 million for municipalities to enable them to cover essential expenses in the first days following the floods. Five more million were issued to allow municipalities to recruit staff for a period of 3 months for the cleaning and repair of roads and damaged buildings as well as assistance to citizens for their administrative procedures.

17 https://www.wallonie.be/sites/default/files/2021-08/cp_gw_assuralia_19-0821.pdf

Reconstruction and Learning

Several months after the disaster, much of the infrastructure works in the flooded areas are well under way with timeframes ranging between several months to years, yet many affected residents are struggling to cope with the aftermath. Although insurance payouts have been mostly completed swiftly, several local residents were still waiting to receive their payouts, making do with their savings and repairing as much of the damage as possible themselves.

To coordinate the immense reconstruction efforts, the Walloon government set up a Special Commission for Reconstruction (CSR) less than two weeks after the floods swept through the region. During a period of at least one year, the CSR will coordinate regional reconstruction efforts and coordinate with the different levels of sub-regional reconstruction, including the Governors of the five Walloon provinces and the Federal Support Cell (CAF) set up after the disaster to bring together representatives of the Police, Civil Protection, the Army, Public Health, Red Cross and firefighters (operational until February 15, 2022). The CAF was set up to assist, when necessary, for example for clearing work, continued removal of waste and psychosocial assistance for victims and members of the emergency services, to speed up the shift from a recovery mode to a reconstruction mode.

As part of the reconstruction efforts, the Walloon region has mobilized substantial funds for the repair of damaged regional infrastructure, such as roads, tunnels, waterways, storm basins, waste management. In total, EUR 800 million are allocated for reconstruction of public works in the affected areas, as per the Wallonia Recovery Plan budgets. At the level of riverbanks, which in Wallonia are often straightened with grey infrastructure, the Walloon Region carries out all works where it is the bank owner and supports municipal bank owners with a contribution of up to 50% (in line with the municipal disaster categorization). In addition, the Walloon government provided support for uninsured public property belonging to local authorities. These include roads, public spaces, bridges, buildings, nurseries and sports centers. In light of the enormous costs of the recovery and reconstruction, the Government of Wallonia signed a financing agreement for a historic amount of EUR 1.1 billion with the European Investment Bank (EIB). The financing will be used to renovate and improve the energy efficiency of social housing (EUR 800 million) and support the reconstruction of approximately 230 km of damaged banks of non-navigable waterways (EUR 300 million).

To address the shortage of construction labor, the region took measures such as a pilot training bonus of EUR 2’000 net for each jobseeker and learner at the Walloon Institute for Work-Study Training and Self-employed and Small and Medium-Sized Enterprise (IFAPME) who enters the construction sector. This bonus will be paid in several tranches to first encourage people to start training and to promote access to employment at the end of the training. Further, more than 1’000 training places were created in the construction sector by the end of 2021.

However, as the reconstruction progresses, one aspect seems to take a back seat: instead of considering how to rebuild in such a way that such a disaster does not happen again in the future (“building back better”), the focus in many places is rebuilding to the status quo. There is an initiative in the small town of Pepinster to co-develop new concepts for the completely devastated areas along the two rivers Vesdre and Hoëgne. A participatory co-design initiative led by researchers from the University of Liège with support of the Mayor of Pepinster and funded by the regional government is exploring pathways towards rebuilding the destroyed areas, exploring options for introducing nature-based solutions and recreational landscaping with permeable soils in the destroyed areas along the river. As part of this 10-year project, the municipality of Pepinster is also buying up damaged and destroyed houses along the straightened rivers Vesdre and Hoëgne to expand the space available for the river (a concept that seemed to be met with little approval elsewhere due to the lack of space in the densely built-up valleys).

When it comes to specific lessons from the 2021 floods and how these were managed, the Government of Wallonia set up a Parliamentary Inquiry Commission “Floods” that resulted in a report with a catalogue of 161 recommendations that were formally passed in March 2022, during the plenary session of the Parliament of Wallonia. The Walloon parliamentarians, independently of a judicial inquiry and investigation into the death of 38 people in the province of Liège that is still ongoing, interviewed a wide range of experts and officials from the regional chain of command to identify lessons from the disaster, to understand what went wrong and to highlight what could have reduced the scale of the disaster. The recommendations relate to the various aspects that were controversial or raised questions after the floods of July 2021. These include meteorological and hydrological forecasts and alerts, risk prevention and crisis management, dams and construction art, watercourse management and land use planning. Twenty recommendations relate to the need to foster a “culture of risk” among authorities and the public. In addition, nearly thirty recommendations target necessary crisis management improvements at local, provincial and regional levels, including the recommendation to strengthen the role of the CRC-W as a stronger crisis coordinator. Several recommendations were devoted to the need to improve the management of dams, in particular that of Eupen. It was also recommended to update the flood hazard maps with data from the 2021 floods.

Learning from event is already leading to action by the government. For example, weaknesses in the early warning system are being addressed. A commitment was already signed in July 2021 to strengthen and expand the partnership with EFAS. In parallel, a Cell of Expertise, the CELEX, led by the CRC, is being set up to bring together key players. It will include actors from hydrology, dams, and waterways of all types, the IRM, the rescue zones, the provincial technical services and the Special Commission for Reconstruction, to improve the cross-functionality and quality of flood forecasting and anticipation work, and streamline communication between stakeholders. Similarly, broader exploration of ways to make operational management at the dams more flexible and dynamic is underway, and the government has committed to establishing a legal or regulatory framework for the control and external inspection of dams. In addition, the different stakeholders (RMI, hydrological services, government) are institutionalizing an improved coordination mechanism amongst themselves and with those in neighboring countries.

This includes regular video conferences and fostering analytical capacities with counterparts at the national and regional crisis centers.

As climate change is expected to continue driving up the risk of heavy rain events and other flood disasters, the Walloon government has also decided to strengthen its measures in terms of climate adaptation with an additional envelope of EUR 15 million. These will concern a wide range of issues: securing the availability of energy and water, protection against excess heat in urban areas, reinforced facilities against floods in sensitive areas, public health, protection of natural spaces and biodiversity, etc. Further, the recently adopted Wallonia Recovery Plan includes more than 300 measures responding to current social, economic and environmental challenges as well as the impacts of recent crises, including the summer 2021 floods, aiming at fostering the region's resilience and maintaining sufficient support for recovering from the floods.

Section V: What happened in the Netherlands and Luxembourg

In Luxembourg, the stationarity of "Bernd" over Central Europe led to 12 hours of continuous and record-breaking rainfall. Two of the Luxembourg weather stations recorded new maximums over 24 hours (Findel with 79 mm and Godbringen with 106 mm). At many river gauge stations in Luxembourg, the 100-year flood level was exceeded, with absolute records measured at 15 stations – and noteworthy that prior records were set in winter, but "Bernd" led to a summer flood. The immense amounts of rain led to widespread flooding that affected nearly the entire country with surface and small river floods eventually moving to larger river systems. As rivers broke their banks, damage became widespread. Roads were inundated, power disrupted and drinking water systems compromised. Due to the flooding, water treatment stations were impeded or rendered unserviceable, including those used internationally along the larger rivers. Despite citizens originally being warned to stay in their homes, hundreds of people were later evacuated in Echternach and other regions, with approximately 1'000 people displaced in total. There were no reported severe injuries or fatalities, but the emergency services reportedly carried out over 1'200 weather-related interventions on the 15th of July alone. Material damage was estimated to be around EUR 125 million; ACA, the Luxembourg Insurance and Reinsurance Association, described it as the "most expensive disaster in the history of Luxembourg insurance." Insurers have received claims for damage to 6'500 homes and 1'300 flooded vehicles, most of which are permanently damaged.

In the Netherlands, flooding was particularly bad in Limburg province, both on secondary and tertiary rivers, as a result of local rainfall, and also on the Meuse River as it funneled floodwaters from the entire region out to sea. Gauge levels on the Meuse in the Netherlands reached levels not seen since 1911; it was the highest summertime level in over 100 years in Limburg. Peak discharge was on the order of 1:100 to 1:1000 per year; probability is assessed at roughly 1:200 per year for the Meuse at Borgharen and decreases to 1:15 per year further downstream.

Precipitation forecasts days in advance indicated a high chance of excessive rainfall in the area, whereas peak discharge forecasts were adjusted upwards just before the flooding events began. Nonetheless, as soon as there was clarity in the forecasts on 14 July, the Royal Netherlands Meteorological Institute gave a code red highest warning for Limburg. Over 400 houses in Limburg lost power and on 1July 16, 2021, mass evacuations started. Residents of the villages of Brommelem, Bunde, Geulle and Boulwames were ordered to evacuate on July 16 when a dike along the Juliana Canal, which regulates the Meuse, threatened to break. However, authorities were out during the event inspecting dikes along the Meuse and the breach was rapidly closed by the Dutch military using sandbags.

Some of the worst flooding was experienced along the Meuse tributaries in Limburg. The probabilities of occurrence of the recorded water levels vary widely: at many locations along the rivers Geul, Geleenbeek and Roer, probabilities are estimated to be between 1:100 and 1:1000 per year. Valkenburg, a city of about 16'000 in the south of the Netherlands on the Geul River suffered the worst impacts. There, damage was severe; hundreds of houses were without power, the center of the city was flooded, and three care homes had to be evacuated under emergency conditions. Damage was estimated at EUR 400 million, 2'300 families were affected, 700 homes were rendered uninhabitable, and a bridge collapsed.

Though as a result of the "Bernd" flooding the Netherlands declared national disaster in southern province of Limburg, the early warning system performed well. Overall, across the Netherlands, however, early warnings went out and were heeded, and as conditions worsened evacuation notices were issued as warranted. That no lives were lost was a tribute to luck (had the storm centered on the Netherlands the outcome might have been quite different), coupled with well established, well understood and well-respected early warning systems, implementation of extensive flood risk reduction measures, and well-practiced and well implemented flood procedures and protocols.

Preparedness and Risk reduction

Luxembourg has implemented the EU Floods Directive and is following an integrated flood risk management approach. This work is informed and shaped by significant flood events include the 2003 floods, the Sauer and Alzette floods of 2011, the Syre, Sauer and Attert floods of 2020, and the Sauer and Gander floods of 2016, the latter also being summer floods. Following lessons learnt from flash flood events in 2016 and 2018, Luxembourg created intense precipitation hazard and risk maps and is considering risks from flash floods in the next cycle (2021-20217) of the flood hazard and risk management plans. Before that, only the traditional winter floods had been assessed as leading to significant flood risk. One of the ways Luxembourg has tried to prepare for floods and increase flood engagement and planning is by setting up flood partnerships in communities. They have been tried in several countries; in Luxembourg, this is an association of individual municipalities along a watercourse, with the local fire brigade as the main local partner. There are eight such partnerships in Luxembourg, and during the six-year flood protection cycle, the partnerships meet two to three times to discuss how to tackle problems together, particularly recognizing and avoiding actions that would simply contribute to problems downstream. However, we were told in interviews that, though on paper this makes sense, in real life it doesn't work particularly well because it has no momentum of its own. The first partnership was established in 2010 and in the beginning, there was a lot of enthusiasm and commitment, but it quickly subsided. To really be effective, it seems the teams need more support, and right now the manpower or financial resources are not available to provide that. Consequently, though there are a lot of tools that could be of use to municipalities, they aren't being picked up.

Resilience is increasingly becoming an issue in Luxembourg, though the civil security mechanism through the combined fire brigade and civil security forces (CGDIS) is, so far, less involved. The Ministry of the Interior is asking the population to prepare better. However, the population knows little and feels safe because little is happening; they also assume there will be help from outside the community if things get really bad. This was highlighted in the 2021 floods; for example, there were 100s of buildings that, if they had had a submersible pump, they would have suffered no damage. Moving forward, the challenge will be increasing awareness and encouraging and enabling communities and individuals to think more about what they should be prepared for and how they can do that preparation.

In the Netherlands, following the floods in 1993 and 1995, the national government invested in their "Room for the River Programme" (a USD 2.7 billion program consisting of 30 projects along the Maas and Rhine Rivers). The main goal was "to manage higher water levels in rivers by lowering the levels of flood plains, creating water buffers, relocating levees, increasing the depth of side channels, and the construction of flood bypasses." Many of the elements had been completed by the 2021 summer floods.

Maaspark Ooijen-Wanssum, a nature preserve near the small city of Wanssum, lies at the heart of the new approach. During the flooding it did exactly what it was supposed to, absorbing so much water that levels in parts of the Maas River dropped by 35 cm, enough to avert a major disaster in Venlo and Roermond.

Forecasting/Early Warning

In **Luxembourg**, the early-warning setup is very similar to Germany. Meteorology and Hydrology und thus the government offices that provide weather and flood warnings are kept separate. The national weather service MeteoLux is only authorized to issue weather warnings, but not flood warnings. Conversely, the hydrologists at the water management office are responsible for flood warnings, but cannot issue e.g. rain warnings. Meteolux issues weather warnings, which are published via news media, the Luxembourg weather agency website and the European Weather warning portal https://www.meteoalarm.org/. The weather service publishes the flood warnings of the flood warning service, which are posted through their alert pages[18] on the flood warning portal, their website and in the weather forecast.

The flood warning service publishes flood alerts in case of flooding based on pre-agreed gauge levels. In a preparedness phase, the publication service of flood situation bulletins is inactive. In a pre-alert phase, flood information is published alongside a flood bulletin at the beginning of the pre-alert stage as well as when the situation changes. In the alarm stage, at least twice a day flood bulletins are published if the situation changes. The gauge levels and their predictions for some gauges are continuously prepared and updated, with a forecast time horizon of up to 24 hours.

In July 2021, Meteolux, had warned of intense precipitation, almost at the same time as the water agency warned of impending flooding. Simultaneous activation of both warnings together rarely occurs, suggesting that the significance of the event had previously been underappreciated and that earlier action could perhaps have been taken. PERC research, for example, noted that similarly to the situation in Germany where, despite warnings going out, experts and the population alike were surprised at the height of the rivers. Indeed, the expert group who usually comes together to manage the crisis once warnings are active, only came together in the evening of the 14 July when the main event was already unfolding (that day rainfall broke records set in 2016). A closer collaboration between the hydrometeorological experts and the fire brigades and emergency management group might have prompted a higher level of early action and preparedness.

The first yellow warning was issued on July 13 for July 14. Uncertainty made decision-making difficult. Luxemburg being a small country, a few kilometers shift in a phenomenon can make a big difference. Therefore, authorities are careful with warnings and give them out only when the probability is high. In general, even the day before the event, the models were not clear enough to give the certainty that the main precipitation area would move over the country.

Support from EFAS and other national met agencies didn't help the water management authorities with the uncertainty – they received an informal warning from EFAS on Wednesday July 14. At that time, the team was already active in the warning period and felt the EFAS report itself was imprecise, informal and too late. The forecasters of Meteolux also looked at the DWD predictions, which seemed implausible because they were so enormous. The French weather service predicted less rain. Given that the German and French predictions were contradictory with large differences in regional distribution, it made local forecasts difficult for Luxembourg. Therefore, an orange warning could not yet be issued on Tuesday. They believe the models could not calculate the Lee effect of the Eifel and the Ardennes well.

On 14 at 7:00 the warning level was increased to orange, triggering the national emergency plan, leading to notification to municipalities and the high commissariat for national safety as well as the CGDIS. Additionally, all fire station managers are also informed and asked to prepare for operations. On July 14 itself, the models then began to simulate the situation more uniformly. But there were still big differences between the models. Nonetheless, it was clear to most staff that warnings needed to go out. The challenge was, what should they say? And. at that time there was a direct handover between CGDIS and the crisis unit, which was then responsible for the warning. The combination made it difficult to decide how to warn where.

The warning chain itself was felt to be quite clear. Warnings are issued centrally by the crisis unit; they do this multichannel (i.e. app, TV, radio, other media, etc.). Police and fire brigade warn independently. However, we spoke with first responders who felt the app is not so well implemented. In particular, during "Bernd", the alert App, GouvAlert, didn't work as intended– warnings went out too late because of an IT issue.

18 https://www.inondations.lu/alerts

The population is also informed via the flood website (https://www.inondations.lu/?lang=en), where the information is complemented by reports. Additionally, citizens can register for a "newsletter", or message service by email on the website. The reports are also sent to the various authorities such as civil protection. In the event of a disaster, the crisis unit must be informed. Unfortunately, people didn't realize they needed to read the report linked below the warning and hence did not understand the details. The difference between page and PDF views was evident in the statistics, so this is being addressed by the authorities.

We did not talk with authorities about early warning in the Netherlands, but there is a significant body of work and indeed entire training courses for other nationalities on how Dutch address early warning that can be referred to. It is clear by how the event unfolded in the Netherlands that their basic early warning structure and approach worked.

Response

Since 2018 Civil protection, ambulance and fire brigade in Luxembourg are integrated into one unit – the "CGDIS". The first responders felt there was good cooperation with other countries, and because conditions and impacts in Germany and Belgium were so dire, Luxenbourg sent support, indeed almost compromising their own capacity to respond internally. One of Luxembourg civil defense's significant messages from the "Bernd" floods, in Luxembourg, but also in the support they provided to Germany and Belgium, was that communication and preparation with communities in advance of disasters is really important and something they still need to work on. In the response, small crisis management teams came together locally – the fire brigade, community leaders, community technical services, etc. And in some places that worked well, particularly for early warning; but in some places not so well. Which highlights that this takes work. Communities need to have their own contingency plans and learn to organize themselves to respond to whatever scenario presents itself. The communities the Luxembourg civil protection worked with post-event had a wide range of skills, capacity and experience with crisis planning and rolling out that crisis planning for their communities. Communities with more capacity and experience are more likely to navigate an event better, and make better use of outside aid when it arrives.

Following the floods, the government of Luxemburg has provided EUR 50 million in emergency relief funding to affected households to cover their basic expenses as well as to farms, municipalities and as compensation of businesses whose business operations have been directly or indirectly interrupted as a result of the flood event.

In the Netherlands, the disaster relief and emergency funding in response to the flood events came from three sources. A direct emergency relief fundraiser has been launched in response to the flooding, allowing people to directly donate money to the most affected households and communities. The fundraiser collected a total of EUR 11.5 million, which provided a direct emergency payment of EUR 2'000 to the most affected households. The remaining money from the fundraiser was paid as community emergency relief to local authorities and other local initiatives such as non-for-profit organizations, foundations etc. which suffered from losses and damage. Uninsured losses were covered by the state through the disaster compensation act (Wet Tegemoetkoming Schade, WTS), which have paid out of EUR 13.9 million (as of March 2, 2022).

Section VI: Key Insights

K1 Preparedness – Modeling, Forecasting and Early Warning

K1.1: The weather event "Bernd" was forecast well in terms of precipitation intensity, but challenges remain in terms of precisely forecasting the time and location of intense rainfall due to the smaller scale dynamic development of these weather systems. For such a large area as the Western parts of Germany, more details where the event would take place are needed. For Luxembourg for a long time it was not even clear whether the small country would be affected at all.

K1.2: The flood events were forecast less well. It was difficult to tell which rivers would likely reach what gauge levels, and when. Gauge forecasts were subject to high variability and came with elevated uncertainty, based on continuously changing inputs such as the rainfall totals in a certain area used as weather forecast inputs into the flood models. These uncertainties were not communicated well, which meant that a variable gauge forecast was interpreted as a reduced expected water level locally. Information that came from the flood reporting service and was meant for first class rivers like the Rhine and Moselle but not meant as flood forecast for the smaller rivers weren't adequately flagged and therefore people thought no flooding was imminent overall, for example based on the communication in the LFU RLP press release on 14 July. While this was an accurate forecast for the Rhine and the Moselle, where they said a 2 – 10-year flood would be possible but no extreme flooding, it only said as an add-on that the situation might be different at smaller rivers. This communication was confusing for recipients and widely debated, including in the parliamentary inquiries.

K1.3: Weather forecasters and hydrological forecasters don't work together as closely as they could. There are legal and operational remits of the weather forecasts, in particular DWD and RMI, and likewise of the regional flood reporting and forecasting services. They exchange and pass on information such as weather forecast outputs as an input to flood models, but are not working "shoulder to shoulder" or as sequentially as they could, sharing and discussing their interpretations of the unfolding situation rather than just sharing the raw data itself. There was not a seamless cascade or stream of information that would lead to a consistent warning message.

K1.4: There are still technical limitations to forecast intense rainfall and small creek and river catchments floods in densely populated, smaller-scale middle mountain regions like the Eifel and the Ardennes. Part of the forecasting and early warning challenge that "Bernd" exposed are the technical limitations of water flow and gauge forecasts in 2nd and 3rd class rivers. Many gauges, although their primary purpose is not early warning of floods due to their short lead times, can offer important short-term information to better understand the situation. As the current distribution of gauges at 2nd and 3rd class rivers is mostly aimed at better understanding the water cycle, they are not strategically placed in locations where they could additionally provide flood information. Additional gauges located upstream of settled areas could provide more data for the calibration of forecast models and could serve, in a flood event, as some local warning infrastructure.

K1.5: Technical early warning information from meteorological and hydrological experts was not translated into a meaningful set of messages for the local civil protection and first responder units, or for the general population to lead to the desired, tangible actions. Those issuing, or with access to, said warnings felt unable to or not responsible for translating this technical information, such as 150 mm rain in 48 hours or 5 m water level at a gauge station, into a contextualized meaning for a district or community. At the same time local actors felt unable to do that translation for themselves so they were unclear about what such a rainfall or water level would mean in terms of local consequences – which areas would flood, what damage would ensue, what an appropriate safety strategy (Evacuate? Move to a higher floor?) would be. There is a gap of brokering and interpreting actionable information for the local level based on technical early warnings. This meant that warnings were too generic and unclear and not impact based.

K1.6: Distribution of Early Warning was not as multi-channel and far-reaching as necessary to reach and then alert the population. The EWS in Germany uses diverse channels like Apps, sirens and the media for the distribution of warnings. This is positive, as the use of multi-channel approaches help reach a wider population and allows for redundancies in the system. Weaknesses in the dissemination lists and instructions to regional and national media meant that popular channels like SWR did not receive the request to distribute warnings. No TV channels interrupted the program or ran banners that indicated that people in the Ahr valley, Erftstadt or Pepinster would need to run for their lives. While smartphone Apps like NINA and KATWARN have their user groups, they also have limitations with potential problems in user reach and user ability (in particular the elderly), user settings (such as activating push notifications and alarms during "silent"-mode), and message overload to lead to immediate action. The national dissemination through MoWaS functioned as planned, but third-party connections like between KATWARN and NINA were not. Where KATWARN was used as the primary dissemination channel like in the Ahr district, this was not replicated in NINA due to a technical error in KATWARN. Cell broadcast has not been implemented in Germany and Belgium yet. All of these electronic dissemination mechanisms depend on critical infrastructure like power and mobile network connections, which failed in parts or completely during the event. Mobile loudspeaker announcements from emergency response unit vehicles were limited in reach and technological capability and were often not heard. In many communities across Germany and Belgium, the siren infrastructure has not been maintained, and where still in place is often used only to notify the fire brigade members on call duty, not the general population. Where such audible alarms could have helped wake up the population, like sounding it repeatedly for an extended period of time or using church bells, these options were not used widely. Lessons from floods elsewhere had not been used – for example, in Grimma, Saxony, modern siren systems that can make public announcements and operate independently from the power grid for 14 days had been installed following the 2002 floods.

K1.7: Roles and responsibilities between weather and flood warnings and civil protection orders are not well connected. If extreme situations like this flood event call for special measures (e.g. by running banners on national television) there is currently no authority who can make such a decision and take them to regional or even national attention levels. Flood protection is regulated in national and state water laws, flood warnings are regulated in flood regulations, and civil protection is regulated at state level in the state fire and disaster laws. These are not connected, and not a single authority is entrusted with making a fast and far-reaching decision to protect people in such devastating, rapidly occurring flood situations. At an operational level, the different actors involved in immediate response may not be familiar with each other and don't know what to expect from each other. We identified communication and understanding issues within the warning chain and especially between the state environment offices and the regional dispatch centers and the response units connected to them who received the warnings. These actors don't talk to each other frequently enough and are unfamiliar with each other's work during a crisis. They don't seem to talk the same language when it comes to the content of the warning and how to interpret it. Detailed knowledge about needs and services that can be provided between the weather and flood information services and the responders at the local level is missing.

K1.8: Where civil protection early warning systems like MoWaS are used, both the authorities triggering the warnings as well as the recipients are not always adequately trained to make the most of the system's capabilities. In many cases, MoWaS warnings were not specific to the hazard but used general messages, and the recommended actions were inappropriate to the type and size of the event. In other cases, too many (and sometimes contradictory) messages from the list of options were selected, with as many as 18 recommended actions in one warning. Often, standardized codes which enable warnings in several languages were not used and thus critical information available in German only, based on a manual text field instead of pre-coded information.

K1.9: Insurance loss estimates originally underestimated total insured losses significantly because the processes that led to the extent of this flood were not well understood. The flood extent was underestimated, partially because models relied on available, short flood statistics. Claims experience relied on past flood damage from big rivers, which create different, lower damage patterns than flashy rivers like the Ahr. The average flood claim in the Ahr valley is almost one magnitude bigger than the typical average flood claim, because the flood extent reached further into the built environment and due to the flood dynamics was much more destructive. Insurance also often is focused a lot on better modeling the big rivers where a lot of high values are exposed, but not necessarily trying to cover other, less populated or lower value areas - but we see now that smaller river types also can cause massive destruction. Additionally, the pandemic and other global crises led to several reasons for increased costs for repairs due to inherent post-event demand surge, increased construction and material costs, and the current supply chain problems.

K1.10: Recent experience of floods has led to complacency: Because they had been labeled a 100-year event, the 2016 Ahr floods contributed to the "low" awareness and response in 2021. Many people thought of the 2016 floods as the "benchmark" of what could possibly happen and didn't even imagine something larger. It did not help that the event was covered in the media as an "extreme" event when in fact a 100-year return period event is a "medium size" event according to the EU Floods Directive and a 1 percent annual occurrence chance is not that rare at all. The combination of this recent flood memory with the limited understanding of and clarity in the early warning messages meant that residents and key actors did not understand the size of the event about to unfold when they could have known. Similar challenges were also noted in the aftermath of the 2021 floods in Belgium, which several newspapers quoted "a once in 100 years" event, leading to some believing that this kind of event would not happen again for another 100 years and that hence, there is limited need to build back better.

K1.11: Recent experience of peace and safety can also lead to complacency with particular regard to the role and importance of the civil protection service and the sociopolitical priority the topic gets. Since the end of the Cold War, Western and Central Europe were lucky to live in peaceful times and society lost their "radar" ability to anticipate threats, including those from natural hazards. Scenarios of what could happen and therefore would be trained were reduced to smaller-scale events limited in geographic extent and severity. Personnel, equipment and functional structures were dissolved (in Belgium, civil protection units were cut by two thirds) or underfunded. This was already seen in the coping of the COVID-19 pandemic and now during the flood response (as well as the later response to the Ukraine crisis).

K1.12: Due to complacency and lack of practice and understanding, early warning was not heeded or led to wrong behaviors. One attempt to explain many of the fatalities – besides the demographics and the large skew toward largely elderly and poorer population – is based on the behaviors of individuals and how they assessed their own risk to property and life. Accounts from where and when fatalities occurred indicate that quite a few were not due to the immediate flood situation but occurred later as people realized the extent of the flooding and tried to safeguard cars, equipment, or personal valuables from low lying areas such as garages and basements when it was already too late. This seems to be a common challenge, and activities such as awareness-raising, training and clear communication about the dangers of these behaviors, which could limit loss of life, were insufficient or absent – at least in Europe.

K1.13: The flooding caused by "Bernd" was not unimaginable nor is it the maximum possible flood: From the very beginning until the end of our review, we have heard how this event had been "inconceivable", "impossible to imagine", "unbelievable". Even in assessment and reconstruction reports issued many months after the flood, the text starts with how the catastrophe surpassed anything known before. This is incorrect. Records clearly show that a flood event of a similar scale has taken place in 1804 in the Ahr Valley, and the flood of 1910 there exceeded available gauge records significantly. The same is true elsewhere. Nor, over most of the impacted area, was the "Bernd" flooding a worst-case scenario, as is shown by weather stations like Jalhay where rainfall amounts were utterly extraordinary and could have caused even more damage had they fallen elsewhere, during a different time (coupled with snowmelt and fully saturated soils) or onto the vineyard hills where mudslides would have added to the problems. Additionally, climate change is increasing rainfall intensity, so today's worst-case scenario could feature 10% more water in 30 years. These factors, together, point to the need to take the 2021 floods as a warning and design standard for the future, not as the exception which won't be seen again.

K1.14: Flood-borne debris made both the flooding and the damage worse: Unlike floods on large rivers (Rhine, Elbe, etc.), in the Ahr, Erft and Vedre Valleys the challenge wasn't just the volume of water but also the energy with which it was moving and the compounding effects of flood-borne debris which both resulted in temporary damming of the river, particularly at narrow bridges, and acted as battering rams.
The combination of flood-borne debris and the energy of the water destroyed entire blocks of houses and most of the bridges in the valley, taking out a lot of critical infrastructure along with it. This is relevant when designing for or considering the "potential maximum flood" event – it is not enough to only look at maximum precipitation scenarios. Models also need to consider antecedent conditions (e.g. saturated soils, rain on snow, etc.) and temporary damming by and subsequent failure of natural and built features. The resulting, pulsating flow is challenging the models.

K1.15: Current flood hazard and risk maps are inadequate to capture events like the 2021 floods. They are based on a short instrumental measurement record that requires 100 year and more extreme floods, which are required to satisfy the needs of the EU Floods Directive, to be interpolated. They do not include historical events, despite well documented, that are outside of the instrumental record, and assume stationarity and homogeneity in the flood record data. While existing technical guidelines could somehow already be interpreted such that this incorporation of historical events were possible, they are by far not specific enough or not stressing this topic enough. The "Bernd" floods and others have shown that summer floods behave differently to winter floods and correspondingly yet are not treated separately when calculating the flood return periods. In the US it has also been shown that extreme flood events behave differently than more common flood events and that seasonality is a key determinant (Smith et al., 2018).

K1.16: The current flood maps failed to keep people and infrastructure out of hazard zones: Existing flood maps also failed to provide residents, local government and first responders with the situational awareness they needed to stay safe and act to maximum effectiveness during the event. When flood maps are revised, not taking the historic floods of record, e.g. 1804, 1910 and 2021 into consideration but rather discount these as exceptional, even now that there have been three in the past 217 years, is folly and limits their usefulness.

K1.17: Critical infrastructure was neither robust nor redundant. It was dependent on single distribution lines especially at river crossings and failed alongside the bridges, leading to serious cascading effects, taking out road and rail access, telecommunication, power supply and heating, both adding to the initial chaos phase in the disaster response as well as complicating the recovery efforts.

K2 Response

K2.1: The event highlighted gaps in German and Belgian civil protection services and disaster law: Local, state, and national emergency responders were unprepared for and had not considered a disaster of this geographic extent and long duration. In particular the Ahr valley proved to be difficult given its long and narrow topography. However, these are precisely the challenges of large-scale disasters – the regional and local authorities will take several hours at a minimum to understand what is unfolding, and at least a day to get into the region. Life and death decisions and action will need to be taken at the local level with little or no outside support. This requires balancing between provisioning capacity for high frequency and rare disaster events.

K2.2: The disaster scenarios covered in disaster law, operational manuals and education and training curricula were insufficient for units to respond to the size and intensity of this event. Current disaster practice is limited to a much smaller, spot-like disaster event (such as big bus crashes, chemical spills in industrial facilities or fires in nursing homes) that is not nearly of the geographic scope seen in the consequences from flooding of "Bernd". The size of realistic scenarios that can happen in practice was underestimated due to a variety of factors, but mostly because the recent decade, both in terms of civil protection and catastrophe aid, had been calm and peaceful. This left the response forces unequipped to deal with the situation on the ground. Equipment is not obtained with such a flood scenario in mind, with little consideration for the size of equipment required, the flood-related abilities necessary (off-road, amphibious), and under what conditions it must be operated. Furthermore, often procedures and protocols were still adhered to when they obviously were inadequate for the situation on the ground and where more flexibility by the crisis managers would have been required on site. An approach, e.g like the one by the GRC, to access global resources (such as the ones of the IFRC) and successfully work together to create a good disaster overview and provide effective emergency response in a national crisis indicates that close collaboration between national and international personnel has potential and could be enhanced.

K2.3: Proactive national coordination and support was not possible. Essentially out of political choice, in Germany, the national-level BBK, as well as the Belgian federal civil protection, is not allowed to proactively enter into operation as a disaster unfolds, they have to be requested by the states. Disaster response is strongly federally organized, leading to a wide variety of structures and wide ranges in the size and quality of disaster response equipment. Indeed, the federal civil protection was established almost as an afterthought to represent aid at the national level. This complicated coordination among aid units and delayed action.

Dispatchers were unable to tell which unit would bring what qualifications and equipment, as each state takes different priorities. Aid providers in the state of RLP were surprised how much better equipped other states were, having seemingly prioritized civil protection more than others.

K2.4: Rather than providing the desired support to complement the tasks of local authorities, outside forces tried to do that job instead of the locals. This led to frustration and feelings of incapability at the local level, when instead the right capacity and equipment was missing. Outside support was not complementary, and not making use of “indigenous knowledge”. Instead, local actors were pushed aside and then the task was duplicated by the incoming support rather unsuccessfully, as was reported multiple times especially in the upper Ahr valley, sometimes getting these forces stuck or in a situation where they could not complete their duties.

K2.5 Realistic disaster scenarios preparing for this type of flood, and the corresponding practice are lacking: This large event has shown that the necessary cross-scalar, multi-stakeholder responses; the level of coordination required and the need to act quickly and accurately had not been practiced before. Higher level support was unable to complement local units, to provide technical and logistical aid and capacity and leveraging the situational awareness available from local responders. In Belgium, much of the initial response was coordinated on an ad-hoc basis, with local first responders improvising to set up a crisis room to keep oversight.

K2.6: The equipment and organizational practice for the disaster response and aid organizations was not fit for purpose for this type of disaster event. Shelter and medical assistance units were not equipped for the size of the people nor were they designed to function without critical infrastructures. The different needs of aid had been planned to be in separate locations, but in reality every location had to do everything, despite not being foreseen to operate as a multifunctional aid station. Radio communication for response units was not reliable, robust or autonomous and failed, massively complicating the initial coordination of response.

K2.7: Effectively using spontaneous volunteers to support civil society actors requires planning ahead: Volunteers are critical to the response and recovery efforts of an event the scale of “Bernd”. However, though initial concept and structures for collaboration between official response actors and spontaneous volunteers were developed after the refugee situation in 2015 in Germany, these structures were not leveraged during the response to the 2021 Ahr valley flood, because there was no dedicated focal point just responsible for this. Everyone seemed too busy with their own areas of responsibility. In Belgium, the regional government of Wallonia supported the creation of online coordination platforms that proved useful in directing the large public solidarity into support action on the ground.

K2.8: Different flood maps are needed for emergency response: Current flood hazard maps in Germany and Belgium are designed for spatial planning but are not suitable for emergency response. The maps provide information for the statistical 1 in 100-year flood and for a “extreme flood” which is not clearly defined but often represents a statistical 1 in 200-year event. Once the gauge predictions are outside of these two scenarios, emergency responders have no idea where the water will go and whom to evacuate (for example, the arbitrarily and ad-hoc defined 50m evacuation zone in Bad Neuenahr or the fact that in Verviers, only the straightened river itself was marked as a red-zone, while the areas directly alongside its banks were not marked at all).

K3 Reconstruction

K3.1: In the absence of baseline planning, reconstruction is now unfolding slowly and/or opportunities are being missed: Reconstruction for large disaster events cannot be coordinated and implemented on a reasonable time scale unless it is pre-planned. As part of disaster scenario preparedness and response planning, there should be light-touch reconstruction planning that identifies key opportunities to leverage, who will need to work together, and required timelines. Because this had not been done in the “Bernd” disaster area, stakeholders are forced to choose between reconstruction delays, missed opportunities, and/or uninformed action. There is not enough time to develop a comprehensive reconstruction “master plan” post-disaster, as immediate needs are to be satisfied urgently. The expectations of the actors will never match reality, and neither will their timelines.

K3.2: Reconstruction is currently still mostly aimed at building back instead of building forward. Due to the differing timelines and priorities of those rebuilding, it is not possible to provide a comprehensive reconstruction concept or “master plan” with an ambitious forward look at communal or district level. Different actors having different timelines means that reconstruction takes place at different speeds and without a comprehensive outcome in mind, especially when guidance and incentives for building back better is missing or limited.

K3.3: Reconstruction misses opportunities to include sustainability and modern technology. For fear of increased costs and abuse, due to different funding structures and application procedures, especially when it comes to new and more sustainable energy use, and due to a mix of competing interests and fragmented incentives, introducing newer, sustainable solutions such as district heating and moving away from oil heating, proved to be very hard. An energy vision with a clear aim of where the affected regions want to be by e.g. 2030 was developed as “project outline Solahrtal”, but is not widely supported. Additionally, energy providers and organizations who could have used this as a positive business case and supported the energy transition took instead a more short-term opportunistic view and focus on old technologies to be delivered to customers in a short time frame, gaining a short-term competitive advantage. These missed opportunities that will never be corrected or need to be retrofitted at high cost.

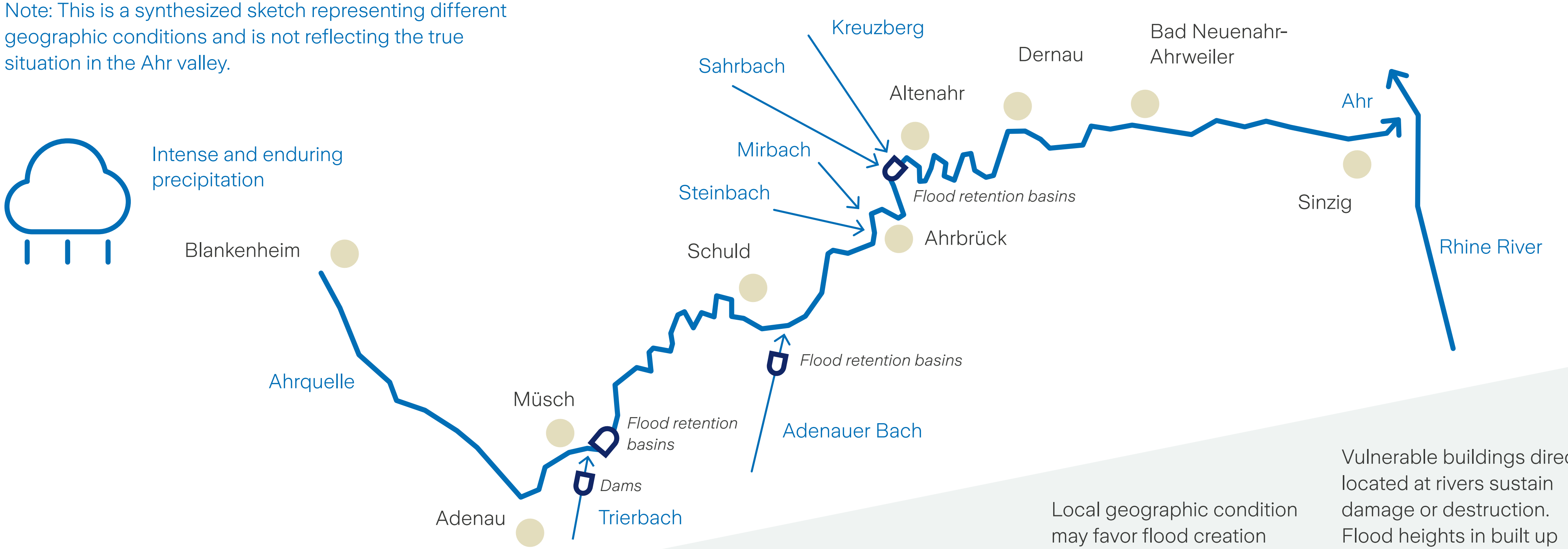
K3.4: The reconstruction and recovery phase of major disaster events could be a powerful opportunity to introduce and utilize nature-based solutions: One of the most powerful ways to address the uncertainty of climate change and the associated increase in intensity and frequency of flood events is by incorporating green and blue infrastructure into existing flood management infrastructure, i.e. shifting towards more nature-based solutions. In particular, leaving space for water along riverbanks and via recreational and agricultural zones reduces the potential for flood damage and generates co-benefits including economic, community, and individual health benefits. Immediately following a major flood event is the most powerful opportunity to make this shift, because everyone involved has a clear vision of precisely why that land should be left open.

Nature-based solutions

WWF together with Stroming conducted a study on the Kyll and Geul rivers in the middle mountains to assess how much "badly" managed soils in the upper catchment contribute to flooding, and how much peak flow can be reduced, and how much base flow can be increased during drought periods. (https://www.stroming.nl/overzicht/possibilities-and-impacts-sponges-approach ; https://floodresilience.net/blogs/can-natural-sponges-help-defend-europe-against-floods/ . They only looked at one simple solution – removing drainage channels and restoring the surrounding small, elongated area to wetlands to delay the discharge of water. Their model shows that if 50% of the available area is restored for sponge capacity, 35% of peak flow is reduced, base flow is increased, and water quality is improved as well. Either farmers need incentives to devote a portion of their land to being "wetland farmers", or the government needs to repurpose land when farmers sell it. However, there is huge potential for such solutions in the Ahr and similar valleys, particularly in the upper catchment.
By how much these approaches can reduce a really big extreme event is currently unclear but part of ongoing research, but clearly grey infrastructure did not reduce the extremes either; and, nature based solutions can significantly reduce damage for a mid-sized flood.

The genesis of flooding and human influence

Note: This is a synthesized sketch representing different geographic conditions and is not reflecting the true situation in the Ahr valley.



Frequency and intensity of rainfall: Climate change mitigation

Rain and river gauges: Monitoring and forecasts

Small creeks covered in narrow culverts

Amount of water entering creeks and rivers: Saturation of soil due to prior conditions; soil management and permeability (sealed surfaces, agriculture, forestry)

Natural flood spaces: Reduces flow speed and flood height downstream

Technical flood retention in side creeks and upper catchment: dams, flood retention basins; Active or passive management may decrease/increase floods

Local geographic condition may favor flood creation

Flood-borne debris carried downstream, adding to damage and blocking underpasses like bridges. Comes from nature (deadwood and trees), from infrastructure (camp sites) and main villages

Vulnerable buildings directly located at rivers sustain damage or destruction. Flood heights in built up environment is increased Additional water enters the river quickly due to paved surfaces (roofs, backyards, roads)

Critical infrastructure and services are impacted by flooding: Main roads, rail, energy and power distribution. Services like hospitals, schools impacted Contamination due to heating oil Waterways for transportation of goods (shipping) impacted. Natural space for river floods in lower catchment has been built over Flood mapping helps indicate areas in hazard zones and take mitigation action Technical mobile and permanent flood protection can reduce damage Early warning can influence behavior and help evacuate people to safe ground

Human influence to manage risk and cause or avoid damage

Section VII: Recommendations

Based on the research and interviews conducted for this study, we highlight below key recommendations that we developed based on input from a wide range of stakeholders across Germany, Belgium, Luxembourg and the Netherlands, and which are relevant both to the areas impacted by "Bernd" and more broadly:

R1 Preparedness

R1.1: A higher density of simple measurement stations for rainfall and river water levels need to be financed, installed, operated and maintained. Current river gauge stations serve multiple purposes besides flood forecasting and are quite expensive to install and operate.
For immediate flood warning purposes, in addition to forecasts of the rainfall-to-runoff-models, simpler measurement stations could be installed in areas of low information density on 2nd and 3rd class rivers and creeks. We were told there are plans to enhance the river gauge network throughout RLP. These simpler stations would be designed to indicate whether water levels are increasing or decreasing and how quickly, and thus could provide additional real-time information in addition to the model forecasts, particularly if coupled with real-time rain gauges. This is of course a personnel and cost challenge. However, some community leaders interviewed for this study told us they'd be willing to install rain gauges themselves just to know in which of the small, dangerous creek areas it is raining and how much. Certainly, a collaboration could be established where local, simpler rain and river measurements are installed and perhaps even "operated" by the communities, with the data integrated into the wider network of the environment offices to improve weather and flood forecasts for the smaller watersheds where capability is limited.

R1.2: Flood models and procedures for flood hazard assessment need further development: To accurately assess future flood hazard, we need to incorporate how climate change is modifying weather systems into our flood hazard and flood risk maps. Hydraulic effects such as blockages from flood-borne debris, morphological changes in the river channel, and the effects of the current and future built environment need to be regularly incorporated - e.g. in the six-year refresh cycle the Floods Directive requires. Without these features embedded in flood hazard assessment, we continue to be unable to assess realistic worst-case flood risk scenarios, will continue to underestimate flood risk, and will lock-in future losses.

- R1.2.1: Historic and maximum possible floods need to be incorporated in flood hazard and risk assessment. We need to look back into the past – much further than a typical human lifespan - in order to understand which areas are exposed to different types of floods, including historical floods that are well documented. Land use planning, delineation of flood zones, and flood preparedness and response measures must also consider these prior, historic floods in their decision-making; they are relevant, realistic, and possibly not even the worst-case scenarios. Hindcast simulations of existing, past floods transferred to the current built environment help outline the scenarios. We recognize that the environment office in RLP has already started a call to the public to report the 2021 flood marks so they can better assess floods and in Flanders, there are dynamic maps of historical floods, which are updated after every flood.

- R1.2.2: Consider revising how legally binding flood zones are derived and what implications they have on land use and building permissions. There is a need to break through the single focus on the 100-year statistical flood. A single flood zone based on the 100-year flood is not nuanced enough and does not outline various levels of hazard, and correspondingly, of risk. Instead, different hazard and risk levels should be outlined, for which different construction restrictions, requirements and protection measures are created. Flood maps should further outline a "maximum possible flood" scenario which is based on a combination of realistic assumptions of what could happen – maximum rain falling on fully saturated soils in the catchment area that creates the biggest, or fastest, flood response. Negative effects such as blockages at bridges etc. need to be considered.

- R1.2.3: Flood statistics should move from a single, homogeneous flood distribution curve to more nuanced approaches, appreciating that seasonality and non-stationarity influence calculated return periods. The behavior of extreme floods may often be different from more regular and seasonal floods and needs to be treated separately in statistical analysis to better account for them rather than treating them as tail events of the main statistical flood distribution, since the signal of these intense summer floods may be masked by the more regular and typical winter floods.

- R1.2.4: Technical guidance for the calculation of flood statistics and the outlines of flood hazard maps need to be revised. Taking above recommendations on updating flood hazard assessment into account, the corresponding technical guidelines at operational level need to provide the necessary guidance and requirements so they are put into practice by the engineering offices doing the fieldwork and calculating the maps. In Germany, this includes updating the DWA and LAWA instructions. It should be considered revising the highest flood laws, such as the EU Floods Directive, to set minimum standards across Europe to homogenize flood risk management, since the competency for implementation is fragmented and often lies at sub-national level, like in Germany.

- R1.2.5: We need rapid models with low calculation times that can predict where water will be for emergency response. For decision-makers, it is insufficient to only receive a forecast of the water level at a single point (i.e. the next gauge downstream) in a river valley. Researchers at the GFZ German Research Center for Geosciences Potsdam have trialed models to show that this approach can work well, using little calculation time (Apel et al., 2022). This can provide authorities ahead of and during the development of flooding not only flood depths across space, e.g. in a city location, but also water speed, which is essential for preserving life. This type of model would improve the decision-making basis to issue evacuating warning.
The implementation of such models could complement the legally

binding flood zones and could be of lesser geographic resolution than the ÜSG flood zones.

- R1.2.6: Model results should be publicly accessible to facilitate update and honest debate. Easy-to-use public portals help a variety of audiences, from experts to laypeople, find and correctly interpret these maps. Particularly in Germany, this should include better access to flood models relevant for insurance, like ZÜRS. A better exchange and discussion between those holding commercial models (model vendor companies), custom models (those built by reinsurance companies) and models for direct insurers is needed.

- R1.2.7: Local flood risk management, insurance and modelers need to come together to provide transparency about how flood risk is reduced following a flood disaster like the one in the Ahr valley, and how such changes can be swiftly incorporated into models to reflect the new situation. This will provide clarity to underwriters in insurance how to assess customers' risks, and will help building owners know how their risk will be assessed and correspondingly insured and take away pressure on the debate of insurability and the need for a state-governed, compulsory insurance scheme that would then likely not be risk-based.

R1.3: Design, performance, prioritization and the use of Early Warning Systems must be strengthened:

- R1.3.1: Design: Current early warning systems fail to provide the predictions needed to inform action in secondary and tertiary catchments, and even in primary catchments provide too little information about potential impacts. Improvements to the current system should be both low- and high-tech. For example, having a communication chain from upstream to downstream communities would, in the Ahr valley, have provided downstream communities with a better understanding of what kind of flood situation was about to unfold. This would provide more actionable information than a simple gauge forecast that can't be interpreted, and would have provided that information a few hours sooner than the official warnings. Higher-tech solutions, such as additional upstream sensors and automatic gauges, would improve the accuracy of forecasts. These could potentially be maintained by local fire brigades or authorities to ensure local buy-in.

- R1.3.2: Performance: Early warning systems only work when every link in the EWS chain works; roles and responsibilities need to be clarified so that there is a continuous and efficient chain of communication from the initial forecast to the individual user. Messages need to be easily understood and coupled with clear prior knowledge or information about what action to take. Non-subscription technologies that are push-based (i.e. are sent to the recipient, rather than pull-based, which are sought after by the recipient) will more effectively achieve broad dissemination of messages. In particular, cell broadcast is a technology well established in many countries and should be rolled out across Europe for any kind of civil protection situation small or large. This could potentially be coupled with a single go-to civil protection warning app that has very high familiarity amongst the population, and can serve as the go-to point for further information and behavior/protection advice.

- R1.3.3: Prioritization: Vulnerable people that need higher attention need to be identified in flood risk mapping exercises and then prioritized when events are unfolding. The cohort of elderly people had a much higher death rate in these floods compared to other cohorts, as did people with special needs. The many deaths like those in a nursing home in Sinzig need to be avoided in the future by providing better alert and evacuation mechanisms to those less able to protect themselves. Similarly, the vulnerability of critical infrastructure and services also need to be better identified in flood risk maps and protected to ensure cascading damage are avoided. The medical base services were significantly affected across the event and three hospitals in Eschweiler, Erftstadt and Leverkusen sustained damage that rendered them inoperable.

- R.1.3.4: Utility: The gap between technical warning messages issued by meteorological and hydrological authorities and the need for easy-to-understand contextualized information on potential consequences required for local first responders needs to be solved. An institution at the level of a state government office could serve as an interpreter, providing a competence and service center that would be available for the first responders in the area under a warning to help them interpret weather and flood forecasts (such as 200 mm rain or 5 m gauge level) and provide access to available flood risk maps that would outline the expected consequences (such as the extent of flooding) for the corresponding forecast.

R1.4: EWS need to be multi-channel, push-and-pull, redundant and contain fail-safe elements. This comprises a combination of:

- Push systems that have high reach capabilities towards the population and a high alarm potential, such as the reinstallation of the sirens, with the added capability of customizable sounds/messages and back-up battery in case of power grid failures.
- Push systems that reach mobile devices instantly – via cell broadcast coupled with improved network coverage and enhanced ability to provide information. Future 5G and 6G technologies will provide more options soon.
- Systems with higher specification potential such as loudspeaker announcements on vehicles roaming the streets.
- Systems with higher information potential such as radio and television broadcasts that can provide clear instructions on what needs to be done, coupled with subscription-based services such as warning Apps (NINA, KATWARN).
- Formalized and partially automated communication structures from weather services to flood forecasters to services that can help interpret the situation to those that need the information – first responders and community authorities.
- Formalized upstream-to-downstream communication structures like in Kreis Mayen-Koblenz, where upper catchment communities are informing lower catchment communities about an evolving flood

situation. Ideally, rather than a linear communication chain from community to community, a higher instance such as a district or state authority such as a potential state civil protection office is charged to provide a clear situation picture to all.

- Human element interactions such as video calls or public announcements by the mayor or respective local authority, and phone calls from head of response units responsible for early warning to other institutions . Warning by voice, which can help transmit the urgency and criticality in the message by conveying the nervousness and fear in people's voices, underlining that it is really serious.

R1.5: To safely 'live with water', baseline awareness needs to be significantly increased: The "Bernd" floods showed the limits of both physical and natural protection; safely continuing to live in flood prone environments requires a transformational shift in how we zone, build, maintain risk awareness, and provide early warning. The "Bernd" reconstruction phase provides an immediate opportunity to begin this transformation.

- R1.5.1: A stronger dialogue about where and how to rebuild needs to take place to balance population pressure with concepts of giving space to rivers. The German and Belgian governments, civil society, and private sector players (especially the construction and insurance industry) should all ask for and participate actively in discussions about where and how construction for private property, businesses, and critical infrastructure is permitted. Permissions must be informed by updated flood maps and recognize that a flood event like "Bernd" can and will happen again. It must be explored how exemptions can be limited to reasonable numbers. It must be avoided that more new risks are created by continuing to build in flood zones. A national, multi-discipline commission for natural hazards (similar to PLANAT in Switzerland) should be created.

- R1.5.2: Make flood hazard visible and part of daily life. Individual and community knowledge about the flood hazard, people's exposure and vulnerability, and what they can do before, during, and after a flood to minimize loss and accelerate recovery must be built and maintained. Annual flood memorial days, historic flood markers, and other visual and periodic reminders are a simple and powerful way to do this, in addition to easy-to-use online natural hazard portals. All households living in flood zones should get regular flyers outlining their hazard - potentially in combination with the flood insurance cover (see corresponding recommendation) or another regular mail.

Flood markers at a central building in Dernau indicating the flood levels of 2016, 1910, 1804 and 2021 (bottom to top). Michael Szönyi, 5.4.2022.

- R1.5.3: The lack of risk awareness across the population needs to be overcome and a sense of self-responsibility created. There are limitations as to what the "government" can provide to the citizens, and at what point a self-responsibility for basic safekeeping needs to kick in. Along rivers behaving as "flashy", fast reacting rivers like the Ahr, the Kyll and many others, residents need to understand how dangerous a 200 mm rainfall event can become, with raging water entering houses and only taking some 10 minutes to rise straight to the uppermost floor, as videos from affected citizens showed. The population needs to be made aware, appropriately educated including in school curricula (climate change, DRR and civil protection as school subjects with practical, interesting things like how to pack an evacuation bag, what documents to take) and ongoing lifelong education, practice drills including evacuation and behavioral drills, so they are able to cope with potentially life-threatening situations, and understand and accept that this will be the new normal and part of a life culture like in other geographies. The tornado alley in the United States comes to mind.

- R1.5.4: Improve understanding of return periods and flood probabilities. A "100- year flood" is often mistakenly interpreted as a flood of a magnitude that will not occur again for another century. It needs to be better communicated that this means there is a 1 percent chance of a flood that size occurring every year. A risk-based approach to decision-making should be forward looking and include the lifespan of infrastructure and buildings. Similarly, flood events should not be characterized as "completely unexpected" or "never seen before".

Usually, flooded areas were often clearly identifiable hazard zones where such events had happened in the past. The frequency and severity of such floods will continue and likely increase in the future. Illustrative language is needed to highlight the consequences, including the frustrations and the irreplaceable losses when living through a flood.

- R1.5.5: Consideration should be given to deal with false alarms (real false alarms where an alarm is triggered with no potential threat) and near misses (where an alarm is triggered because all the physical indicators warrant it, yet e.g. the rainfall then moves to a different valley and no harm is caused), and an understanding created for the difference between the two. Consideration that it is better to evacuate once too often rather than once too rarely needs to be further embedded into an overall understanding of probabilities and uncertainties when dealing with natural hazards and physical events like rainfall and river water levels.

R1.6: Failure of critical infrastructure is itself a disaster and must be avoided or minimized: In the "Bernd" disaster, as is true of all disasters we have studied, critical infrastructure was not robust nor redundant and led to subsequent, cascading failures both in the emergency response and the later recovery operations. The location, the construction, the maintenance, and the investment strategy overall for water, wastewater, power, and in particular communications and transportation must be rethought to ensure these lifelines stay operational. Telecommunication, transportation, power, potable water and sewage facilities are absolutely essential for a society and for the support operations in crisis. Pre-planning both to avoid disruption and to enable rapid re-establishment of critical services should they be damaged needs to be strengthened collaboratively across the private, public and governmental entities involved in their provision and operation. Critical infrastructure needs to be better identified in flood risk mapping exercises and then protected to a much higher level than HQ100. Alternately, or even better additionally, islanding and self-sustaining features like decentralized green power grid and district heating can provide redundancy. Critical services, especially public health services, need to become better protected against flooding and obvious changes in design and operation must be implemented, such as not locating high-tech, highly flood vulnerable equipment into basements, a recommendation made many times before, most notably in our PERC Harvey report.

R2 Response

R2.1: Disaster law needs to foresee intense and geographically expansive natural hazard scenarios like the "Bernd" floods. First response search and rescue equipment and vehicles need to be capable of such scenarios both in terms of number as well as in capabilities (off-road, amphibious, equipment the vehicles can carry). In some cases, the guidelines for how to obtain and finance them, such as through state and national subsidies, are leading to the acquisition of vehicles that are not fit for purpose. The guidelines therefore need to be revised, so that what's required can also qualify for subsidies. Operational manuals and trainings need to reflect these new scenarios, including how multi-function sheltering and first aid stations can be set up and operated.

R2.2: Disaster response needs to be strengthened, restructured and standardized at the national level, supporting the states. While confirming the need to rewrite state disaster law requires a political debate with potentially far-reaching consequences, empowering the national civil protection and disaster aid setup (the BBK) to provide more proactive support to the states and coordinating and facilitating tasks that can then be executed at the state level, should be considered. Others, such as the RLP learning report, have suggested the creation of a state office for civil protection and catastrophe prevention ("LABK"). This might improve the effectiveness of response within the state, but does not solve all the issues by just looking inward. More importantly, better coordination with other states and additional response capacity, supporting the local level who knows best what needs to be done, is necessary. It should be considered whether this could not most easily be achieved by strengthening an already existing body, the BBK.

R2.3: Disaster law needs, as part of the recommendation above, certain standardizations in terms of structures, definitions, equipment and personnel. Operational structures need to be clarified, including the alarm levels and corresponding duties and meanings, starting with how to declare a disaster ("Ausrufung des Katastrophenfalls") which would then provide legal and case competency across the nation. In terms of equipment and personnel capacity, minimum requirements incorporating learning from massive disasters such as the "Bernd" floods should be established, to which all states would need to adhere to when obtaining disaster response equipment and when setting up structures how to operate them. This must ensure they are compatible with each other, starting with seemingly simple things like radio communication of different response units up to compatibility of search and rescue equipment or shelter materials. At state and national level, heavy duty search, rescue and recovery equipment needs to be available for dispatch where it is impractical or too expensive to be continuously available at the regional or local level, including helicopters with night-time and winching capabilities, which had been a big issue in the first night of the floods. Federal and local contextualization above these minimum standards should still be allowed to account for local differences in need, e.g. special needs in a more mountainous state like Bavaria compared to a coastal state like Schleswig-Holstein. A national disaster response inventory database should be set up that can be quickly accessed by dispatchers in a disaster situation, such as scanning a QR code of the lead vehicle of a unit to get an instant overview of the size, equipment, and capabilities of that unit.

R2.4: Trainings and processes should be regularly practiced to make response more effective: Education and practical exercises for large-scale and complex emergencies help build the capacity and networks of response actors needed to allow them to respond quickly and effectively to real events. Codifying these processes could prove useful for future flood events and also for other large-scale and complex crises (e.g.

pandemics or refugee situations). Trainings should be tailored to the location – in small, flashy catchments like the Ahr Valley, the focus should be on evacuation and saving lives; in large rivers and catchments, once it is clear evacuation and life protection has been addressed or not needed, attention can shift to protect assets. Training can also support emergency responders to prepare for complex scenarios that include compound river and surface water flooding, and cascading effects such as collapse of critical infrastructure, communications lines. Trainings and operational manuals must ensure the collaboration between local, regional and state / national actors are clear and practiced and adhere to the needs and follow the guidance of the local crisis managers.

R2.5: Local civil protection forces should be strengthened, and where possible complemented by professional and full-time forces. Given their current mandate and resources, local response forces such as volunteer firefighters and ambulance and shelter workers do not have the skills or capacity to respond to an event like "Bernd". Though they did what they could and made a difference, virtually all local, volunteer forces in the disaster area were overwhelmed. To be better prepared for future events of this scale, civil protection forces need education, continued training, and hazard-specific equipment. To reach the necessary breadth in coverage such as local fire brigades, the volunteer concept is strong and needs to be kept, but it must be supplemented. Local volunteer forces need to be supported by professional, full-time forces and local, skilled administrators who can develop the necessary alarm and dispatch protocols and collaborative response scenarios needed for big events (e.g. large-scale floods, wildfires). Professional experts must be able to react flexibly and specific to the situation and not be caught in hard-coded procedures. Volunteering forces and the fire brigade should learn, train and work alongside the other resources, for example in a combined civil protection academy.

R2.6: Better knowledge and an inventory where vulnerable people are exposed to a disaster scenario will help speed up and prioritize evacuations. Information on where vulnerable people are located and what their special needs are should be accessible to emergency responders to prioritize during evacuations and be able to plan ahead to allow for the additional effort and time that may be needed. Similarly, such information must be shared with first response, aid and health service organizations to better coordinate disaster recovery support, so as to target and tailor it to those most in need.

R2.7: The integration of spontaneous volunteers needs to be pre-planned into existing civil protection structures. Lessons learned from this flood response should be integrated into future collaborative structures and dedicated volunteer focal points in the crisis unit and larger response organizations should be appointed. There is a need to create systems so spontaneous volunteers can be equipped with personal protective equipment and to include them into the workforce planning.

R3 Reconstruction

R3.1: Disaster law needs to outline, ex-ante, how reconstruction will work and what timelines are required - a "Reconstruction master plan":

- R3.1.1: Financial and planning instruments for building back better need to be designed and ready before an event. Once the event has happened there is an urgency to recover and then rebuild quickly; if this is coupled with ad-hoc decisions, it can lead to lost opportunities at best and maladaptation at worst, such as new oil heating systems being installed into damaged homes right after the flood rather than taking the time to design and invest in a whole-community heating solution in Germany. Rigid reconstruction rules that miss out on additional opportunities (because e.g. separate funding streams are isolated or because these would require adding technical skills to the corresponding approval procedures) need to be avoided. Good practice such as the participatory co-design initiative in Pepinster can serve as examples for harnessing the opportunity that lies in disaster to find new, more resilient land-use options.
- R3.1.2: Event learning should immediately be incorporated into spatial planning to support building back better. A key priority area should include using the event to identify where additional space for water is required, coupled with avoiding reconstruction exemptions. Structures damaged in this event will, if built in the same way in the same location, eventually be damaged again. Enabling, encouraging, or forcing people to build back in high hazard locations should be avoided. In particular, regulations that only pay out if people build back in the same location or the same way need to be immediately changed.
- R3.1.3: Green and flood resistant reconstruction of buildings and infrastructure should be encouraged; the post-flood reconstruction is an opportunity to build in greater energy efficiency and mitigate risk. For this to be successful, however, there needs to be prior awareness of greener options coupled with a realistic timeline for reconstruction decisions that supports rebuilding better. This could be led by construction firms, insurance, or government, rather than putting the full responsibility on home- and small-business owners already overwhelmed by the need to rebuild.
- R3.1.4: Competence centers and technical support and guidance capacities need to be put in place so decision-makers unfamiliar with technical flood risk aspects can get answers they need to build back better and more adapted to flooding. Planning for building back better and executing the master plan needs to be funded alongside the reconstruction cost itself and not come from separate, difficult-to-access pots.

R3.2: A "Flood Delegate" and special "Flood Zone" should be designated after a disaster to speed reconstruction:

- A "Flood Delegate" responsible for and with full overview of the reconstruction could improve coordination and ensure that a wide vision for reconstruction can be implemented. The delegate would coordinate across various institutions; keep the full picture of goal, actions, activities and outcomes; and work with special competencies and permissions.

- A special "Flood Zone" should be legally designated in which special flood emergency laws can be implemented that help with timelines and requirements for reconstruction, permits, etc. The current reconstruction is being slowed by bureaucratic processes designed for different conditions and purposes and imposed without review on the current situation.

R3.3: Do not provide undue ex-post compensation for those that could have insured. Elemental cover should be considered as part of a holistic concept between government and the economy. For new and existing contracts, provide risk-based offering for elemental coverage with limited op-out clauses. Ensure that consumers understand that if they don't take out flood insurance based on their own decision, as a consequence, they might be denied compensation rights. Unconditional und unplanned compensation leads to a series of disincentives to not protect adequately against flooding and to not give space to rivers.

R4 Risk Reduction[19]

R4.1: Flood risk reduction at individual and property level must be strengthened, become more standardized and easier to implement using practical and established solutions. In some areas, guidelines, expert support and eventually, flood protection certification is already available, such as the Flood Pass or "Floodlabel" from the Flood Competence Center in Cologne[20]. Combined with insurance, flood risk reduction needs to be improved at property level to counter increasing loss trends. While insurance can help identify flood risks and make recommendations, the large number of properties at risk require a dedicated facility support the motivation for and uptake of measures. An independent, non-profit facility like Floodlabel could help improve the building stock in Europe.

R4.2: Risk reduction measures need to be incentivized by insurance and government funding and supported by the construction industry. Many solutions are easy to implement, are no- or low-regret, provide well-established benefits and could be included at very low or even no cost for new construction. The right incentives need to be set that they are offered and discussed in every new project. Insurance and government can support through premium or deductible incentives or by co-financing. Simple protection measures include raising lightwells of basement areas, using flood-resistant windows and doors or temporary flood-proof fixtures instead of sandbags, facilitating natural infiltration and sloping ground away from the house so that water can run off rather than run towards the building, and ensuring that gutters are kept clean and dimensioned according to expected rainfall.

R4.3: Mandate to make all installations with contamination potential, especially heating oil tanks in private homes, flood proof. Severe contamination by floating heating oil, including the late condemning of properties that were already in the rebuild phase or downstream would all be easily avoidable by anchoring down oil tanks and keeping them safe from ruptures and water entry; flood-proofing heating plant rooms to keep them undamaged; or using alternative energies that do not cause contamination in the first place – all established measures that don't get implemented for reasons explained in R4.2.

R4.4: Don't reconstruct without an overarching flood protection plan finalized and transparently published, drawing on a learning process from the flood. There needs to be an honest discussion and decision-making process on how to reconstruct in a truly transformative and more imaginative way. For example, is it really desirable to reconstruct the railway again in a narrow valley where the river urgently needs more room, or would it be better to find alternative solutions? Is it really adequate to push the river back into a narrow bed using heavy equipment rather than use part of its new course as a natural waterway? What should the reconstruction process look like, how much more space do you provide to the river and how much do you extend the legally binding flood zones? All these questions need to be answered as part of an integrated flood protection plan before reconstruction can begin (see R3.1 and R3.2). This is particularly true for all the critical infrastructures – the bridges, the power, telecommunication, gas, and electricity. Key questions to be answered – are they located outside of areas that can flood, if not how high and robust are they built, how do you adequately protect them and provide the necessary freeboard for water to run free.

19 Risk reduction here is meant integrally, not just the reduction or avoidance of extreme events, but also smaller but still often costly and damaging events.

20 https://www.hochwasser-pass.com/ and https://www.floodlabel.com/

Ways Forward - 'Nobody listens'.

As populations increase globally, we are expanding human settlements and infrastructure into higher hazard zones at the same time that climate change is amplifying the risks across many regions. If we want to live safely, we need to learn quickly from our challenges and failures in addressing risk. There is a wealth of information and learning resulting from the "Bernd" flooding. We need to create platforms to share and amplify these lessons and support their uptake into policy, investments, and practice.

Most important, risk reduction efforts should not be concentrated (and potentially overdesigned) only in areas impacted by "Bernd", and learning not exclusively kept to those affected in the most recent floods. Instead, this event should be used as an opportunity to strengthen systems across Western Europe. In 2002 and 2013, severe floods already devastated the villages and cities located close to major rivers, especially in the East, and many lessons have been learnt in those regions. And then, some have not been learnt. The city of Grimma was heavily affected by floods from the Mulde river in 2002, so badly, that the conclusion was clear: "Grimma, never again". Plans were put in place to improve flood protection, to build back better rather than reconstruct. But eleven years were not enough. Grimma flooded again in 2013, with the plans still not implemented.

> We hope that what happened in Grimma does not happen to us – that the flood comes again.
>
> Local resident in the Ahr valley

Yet, under a federal system that is often inward-looking, learning seems to be unable to cross boundaries and reach other states and nations as well. Learning from past events do not reach others who could be impacted in future. If modifications to the structure and the operational cooperation between states before, during and after crises are not made, then, it seems, lessons can only be learnt after events have affected each and every state or region.

Investments into the future are sometimes difficult decisions containing much uncertainty. We see this in the debate about climate change mitigation, where implementation is slow and financially underserved. As a consequence, the climate impacts will be arriving sooner, more intense, more frequently. This means we now need to find the sociopolitical will to invest in climate change adaptation, and in this particular case, in flood prevention. If designed cleverly, they provide many additional no-regret benefits, they will have outstanding benefit-to-cost ratios, and they will be fit for the long-term future. But of course, there is always a trade-off. There is financial pressure to invest in flood prevention (and only see it as a cost, not an investment) compared to investing in other development areas. On that financial aspect, one has to note that ex-ante spending for risk reduction is often hard to get because – well, nobody listens and the benefits are not evident enough. After a big flood disaster, however, it seems always easy to provide relief and reconstruction money, at a multiple of the original cost. If we want to achieve transformational change and break through the pattern of build-flood-lose-rebuild, we must invest now. Looking at available space, there is always a pressure to provide more housing and commercial areas, which hinders natural flood protection and providing room to rivers and their biodiversity. But if we can't find a better trade off and avoid our future built environment, and many vulnerable people alongside it, is located in low lying areas ever more subject to flooding, and only provide very incremental solutions, then we arrive at the initial situation outlined in the foreword – we then must accept, and face the consequences, that the desired final picture of a flood resilient community well adapted to the future challenges is not obtained from the puzzle pieces of incremental, ineffective and piecemeal changes that can be implemented without the will to put in more effort, without the societal discussion that something has to change. Raising the bridges a little, providing more space for the rivers in city parks, roofs holding back the water, not reconstructing in flood zones except where there are exceptions – it all sounds nice but is by far not enough.

Time is running and flood dementia is already setting in. Let's use the momentum to indeed achieve the picture we want to see at the end, a flood resilient community, in the Ahr valley, Erftstadt, Pepinster, Liège and elsewhere. Remember that in addition to all the people that lost their life in the event, the total estimated loss in Germany alone was over 30 billion Euros for one valley and a couple more hot-spot areas and compare this with the total exposed assets in the country and on the continent.
What damage would the next event cause to society, and how much more could be achieved by spending the money much more sensibly up front?

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About the Zurich Flood Resilience Alliance

The Zurich Flood Resilience Alliance, a multi-sector partnership focusing on finding practical ways to help communities strengthen their resilience to floods globally – and save lives – was launched in 2013. In the first phase of the program, we have reached over 225,000 direct beneficiaries across our 13 programs in nine countries.

In the second five-year phase of the program launched in July 2018, the Alliance aims to increase the investment going into pre-event resilience building by USD 1 billion and commits to scaling up its work in climate action, to help make 2 million people more resilient to flooding, both by the end of 2023. We already know that every USD 1 invested in prevention saves on average USD 5 in future losses. We do this by rolling out best-practice community programs that demonstrate the value of resilience-building; compiling best practices and success stories; and advocating for more investment in resilience with authorities and public and private funders. We share our knowledge on our own flood resilience portal.

This Alliance is now comprised of nine members – Zurich Insurance Group working with the civil society and humanitarian organizations Concern Worldwide, the International Federation of the Red Cross and Red Crescent Societies (IFRC), Mercy Corps, Plan International and Practical Action as well as research partners the International Institute for Applied Systems and Analysis (IIASA), the London School of Economics (LSE) and the Institute for Social and Environmental Transition-International (ISET). Funding for our Alliance partners is provided by the Z Zurich Foundation.

About PERC

As part of the Zurich Flood Resilience Alliance, the Post-Event Review Capability (PERC) provides research and independent reviews of large disaster events. It seeks to answer questions related to aspects of resilience and disaster risk management. It is a flexible method that analyses the root causes of why events become disasters. It looks at what has worked well (identifying best practice) and opportunities for further improvements. Since 2013, PERC has analyzed various flood and wildfire events and won two awards. It has engaged in dialogue with relevant authorities, and is consolidating the knowledge it has gained to make this available to all those interested in progress on disaster risk management.

Concern worldwide | IFRC | IIASA International Institute for Applied Systems Analysis www.iiasa.ac.at | ISET International | LSE The London School of Economics and Political Science

Mercy Corps | Plan International | Practical Action | Zurich