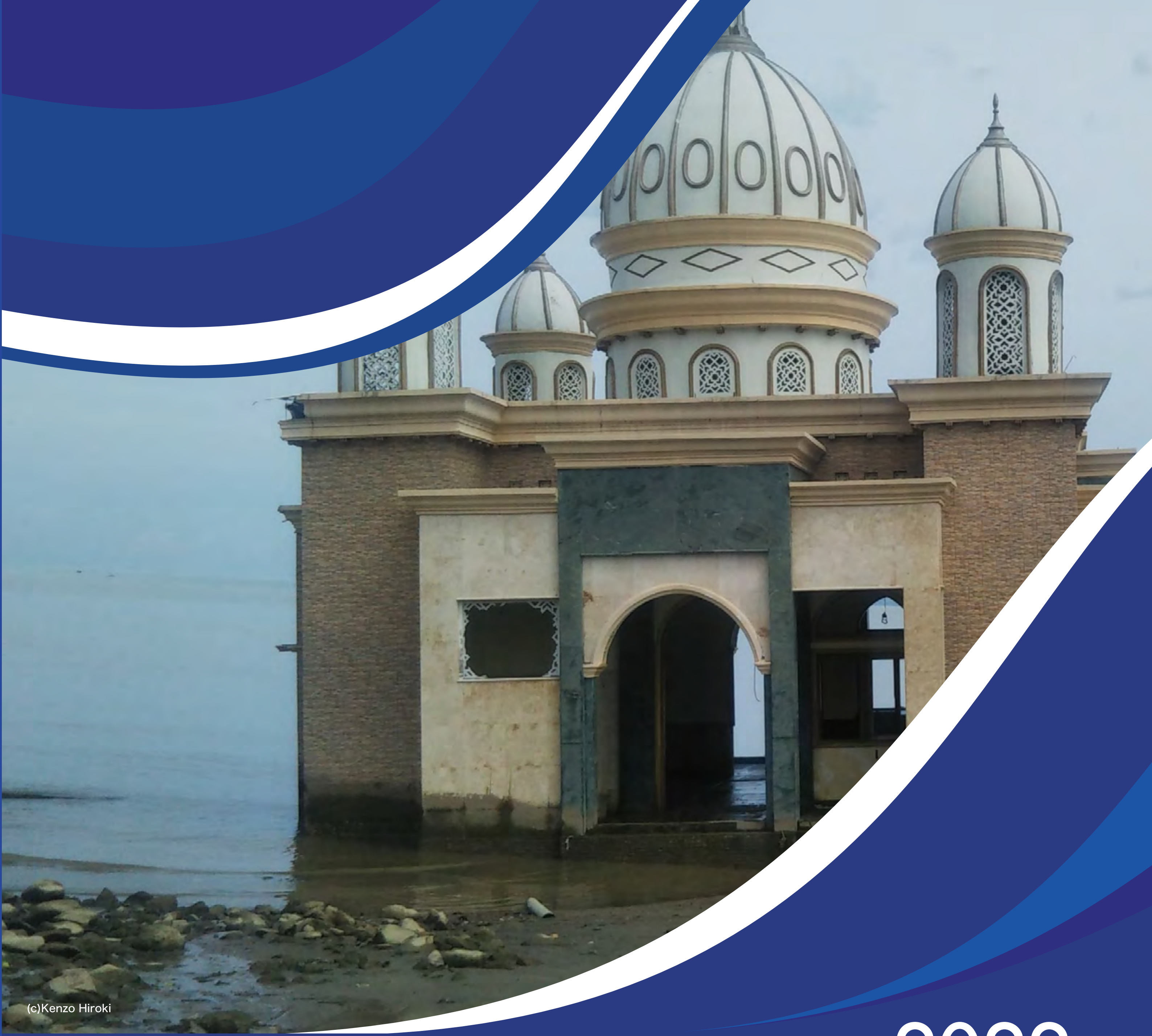

(c)Kenzo Hiroki

2022 HELP Global Report

on Water and Disasters

Table of Contents

Preface

Dear Readers,

I am pleased to share with you this HELP Global Report on Water and Disasters 2022, the fourth edition in this annual series that compiles the experiences, lessons, and good practices of the past year that address large scale disasters on earth.

Water-related disasters have kept impacting countries socially, economically, and politically worldwide. Heavy rains and ensuing floods in Europe in July caused a death toll of over 200 people and billions in economic losses. Disasters of this scale or larger may now happen anywhere in the world given the accelerated pace of climate change. They know no borders and hit people and communities irrespective of time and location.

While disasters continue to happen on earth, the waves of COVID-19 have severely impacted countries, and continue to do so until now. The pandemic starkly demonstrated how our societies and systems were unprepared for sudden shocks and disturbances. It also demonstrated how decision-making by our leaders needs to be quick and evidence-based. Here, science and technology play a critical role. For this, we should position science and technology as "a game changer" for building a fully resilient post-corona society, through the following three actions: (a) Promote water cycle consilience by accelerating an Open Science policy, particularly focusing on observation, modeling and data integration; (b) Foster "Facilitators," that is, catalytic leaders who can show the way toward resolving problems by providing professional advice on-site, using a broad range of scientific and indigenous knowledge; and (c) Work together beyond disciplines and sectors among different levels while taking an end-to-end approach.

During the Asia-Pacific Water Summit in Kumamoto co-hosted by HELP, which took place in Japan in April this year, eighteen Heads of State and Government intensely discussed how the world can build back better from the economic, societal, and political devastation triggered by the pandemic. They concluded that we should transform our society to a quality-oriented one that is far more resilient, sustainable, and inclusive than the prior COVID-19 one. They agreed that water should play the central role in this global transformation. Connecting policies and actions on climate change, water, and disaster risk reduction, through water is the first and inevitable step countries should take.

Issues of peace and regional stability were also put on hold in international politics during the 2021-2022 pandemic period. Yet, disasters can trigger animosity and conflicts among riparian countries. A crisis can cross watersheds. For example, floods and droughts in a basin may cause food shortages, epidemics, and migration that spread throughout regions. However, history also informs us that there are more cases in which disasters have fostered peace, rather than conflicts, triggering collaboration and solidarity among countries and their citizens. The "HELP Principles to Foster Peace before, during, and after Water-related Disasters", launched in April 2022, is the first product to shed light on some of the keys that enable parties to join hands toward peace, by turning crises into opportunities.

As major disturbances, including disasters, pandemics, and peace crises, will keep happening, there is only one path to human survival: to keep learning and be progressively better prepared for when the next catastrophe strikes. My sincere hope is that this edition will help readers be better prepared for disasters, as inevitably they will occur, perhaps even as soon as tomorrow. We need to be ready.

Dr. Han Seung-soo
Chair, High-level Experts and Leaders Panel on Water and Disasters (HELP)
Former Prime Minister of Republic of Korea

As I write these words, communities in Puerto Rico, Florida and throughout the Southeastern United States are recovering from the impacts of Hurricanes Ian and Fiona, both of which made landfall in September 2022. Whether drought, wildfire, or hurricanes, these extreme weather events continue present a threat to our nation's infrastructure water resources. The U.S. Army Corps of Engineers (USACE) continues to collaborate with an array of partners to develop technologies, innovations, engineering and science across our entire enterprise to combat these extreme events.

Our contribution to this publication revolves around Hurricane Ida (Aug 29-Sep 2, 2021)—the second-most intense hurricane on record to strike the U.S. state of Louisiana, behind only Hurricane Katrina (2005). After making landfall with maximum sustained winds of 240 km/hr, the storm turned northeastward and caused severe impacts over a broad swath of the Northeastern U.S.

While the significant effects of Hurricane Ida were felt across the region, USACE applied its lessons learned from Hurricane Katrina to prepare for, respond to, and ultimately lessen the storm's overall impact. Prior to the 2021 hurricane season, joint exercises were conducted to test physical and cyberinfrastructure. Several days before Hurricane Ida's arrival, releases of water were made at reservoirs, following established water-control plans, as a means of storing additional storm runoff. At the request of the Federal Emergency Management Agency, USACE "activated" various emergency operations centers along the path of the storm, and more than 2,000 individuals were deployed to work on the ground, while another 500 provided support and coordination from home stations.

While we, along with our partners, were able to minimize the storm's impacts, opportunities remain for USACE to improve. This year, we published our first Climate Strategy, which addresses the potential increased risks from higher temperatures, changing precipitation patterns, more intense storms, and higher sea levels. In response, USACE continues development of tools to assess these risks, both domestically and internationally, and on and off our military installations.

We welcome collaboration opportunities with our international colleagues, through HELP, and other multilateral frameworks, to help reduce disaster risks at a global scale.

Essayons! Building Strong! Army Strong!

Lieutenant General Scott A. Spellmon
Chief of Engineers and Commanding General of the U.S. Army Corps of Engineers

Overview of Water-related Disasters in 2021-2022

1. Overview of Water-related Disasters and Challenges of Disaster Risk Reduction under COVID-19 in 2021

Kenzo Hiroki
Professor, National Graduate Institute for Policy Studies (GRIPS) and Coordinator of High-level Experts and Leaders Panel on Water (HELP)

Water-related disasters in 2021 resulted in death toll of 6,500 (of which 6,000 by flood and storm), affected people of over 99 million (of which 52.7 million by drought), and economic loss of 224 billion US Dollars worldwide. Having experienced COVID-19 and recurrent disasters, it is imperative to build back better towards quality-oriented society that is more resilient, sustainable, and inclusive.

1.1 Human loss and number of affected people by water-related disasters in 2020

The year 2021 was characterized by recurrent water-related disasters under the continuous infection waves of COVID-19, which was threatening billions of people worldwide. In 2021, 6,493 people lost their lives by 373 water-related disasters (e.g., floods, tsunamis, slides and debris flow, storms, and droughts) out of total yearly death of 10,492, meaning that 62% of deaths were caused by water-related disasters.

According to EM-DAT (International Disaster Database) of Centre for Research on the Epidemiology of Disasters (CRED), 99.5 million people were affected by water-related disasters out of 101.8 million of people affected by all disasters, meaning 97.7% of disaster-affected people were caused by water-related disasters. Share of death by water-related death (62%) is much higher than the average of the recent 20 years (29%). Death Toll by Disaster Type (2021 vs. average 2001-2020) are shown in Figure 1.1. Top 10 severest disaster events by number of affected people in 2021 are shown in Table 1.2. In Europe, heavy rain and flooding in Germany, Belgium and other countries resulting in deaths of over 220 people gave economic, social, and political impacts in the Region (Picture 1.1).

The increasing trend of number of affected people by water-related disasters continue due to, inter alias, climate change, population growth, and urbanization. In the recent twenty years (2001-2020), number of people affected by water-related disasters is 3.76 billion and accounts for 97% of total (3.87 billion).

Table 1.1 Death Toll by Disaster Type (2021 vs. average 2001-2020)

Event	2021	Average (2001-2020)
Drought	0	1,059

Earthquake	2,742	37,942
Extreme temperature	1,044	8,684
Flood	4,143	5,185
Land slide	474	884
Mass movement (dry)	0	37
Storm	1,876	10,442
Volcanic activity	85	89
Wildfire	128	77
Total	10,492	61,212

Source: UNDRR using EM-DAT (International Disaster Database)

Table 1.2 Top 10 severest disaster events by number of death in 2021

(Bold letter by water-related disasters)

Country	Name of event	Death toll
Haiti	Earthquake	2,575
India	**Flood**	**1,282**
Canada	Heat Wave	815
Philippines	**Typhoon Rai**	**457**
China	**Flood**	**352**
Afghanistan	**Flood**	**260**
USA	**Winter Strom**	**235**
India	**Landslide**	**234**
USA	Heat Wave	229
Indonesia	**Cyclone**	**226**

Source: 2021 EMDAT Report

Table 1.3 Top 10 severest disaster events by number of affected people in 2021

(Bold letter by water-related disasters)

Country	Name of event	Death toll
China	**Flood**	**14.5 million**
South Africa	**Drought**	**12.0 million**
Afghanistan	**Drought**	**11.0 million**
Philippines	**Typhoon Rai**	**10.6 million**
Iraq	**Drought**	**7.0 million**
Somalia	**Drought**	**5.6 million**
Ethiopia	**Drought**	**5.5 million**
Syrian Arab Rep.	**Drought**	**5.5 million**
Iran (Islamic Rep.)	**Drought**	**2.6 million**
Kenya	**Drought**	**2.1 million**

Source: 2021 EMDAT Report

Picture 1.1 Damage to railway along Ahr River by Heavy Rain Disaster in Germany in July, 2021

Photo by Kenzo Hiroki

1.2 Economic loss by water-related-disasters

The overall economic loss by water-related disasters in 2021 was US$ 224.7 billion, or 89% of total loss of US$ 252.1 billion by all disasters. Tropical cyclones, hurricanes, and typhoons hit and caused severe damage in various parts of the world. The annual loss of 210 billion USD was 153% of the average of US$ 146.8 billion in the recent twenty years of 2001-2020.

Table 1.3 Top 10 severest disaster events by economic loss in 2021

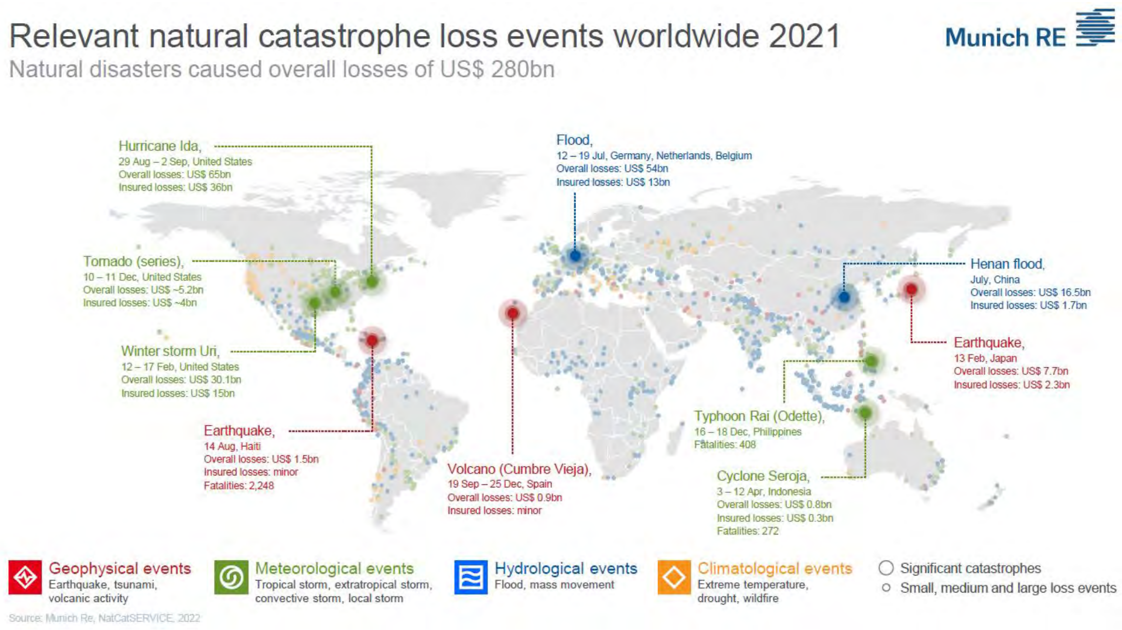
(Bold letter by water-related disasters)

Country	Name of event	Death toll
USA	**Hurricane Ida**	**65.0 billion**
Europe	**Flood**	**54.0 billion**

USA	**Winter Strom**	**30.0 billion**
China	**Flood**	**16.5 billion**
USA	**Drought**	**9.0 billion**
Japan	Earthquake	7.7 billion
France	Cold Wave	5.6 billion
USA	**Tornado**	**5.2 billion**
USA	Wildfire	3.3 billion
China	**Drought**	**3.2 billion**

Source: 2021 EMDAT Report with addition by Munich Re. Fact Sheet

Fig. 1.2 Map of natural catastrophe loss events 2021



Source: Munich Re. Natcast 2022

1.3 Major water-related disasters in 2021

Disasters know no border. Major water-related disaster events include Hurricane Ida in the U.S.A., Typhoon Rai in the Philippines, heavy rain and floods in Europe in July, and droughts in Africa, Middle East, and Asia.

Heavy rain and floods in Germany, Belgium and neighbouring countries in July, 2021 gave significant social and economic impacts in European Region. Death toll reached over 200 in Germany only. The water disaster gave lots of lessons on preparedness. A mayor in Ahr River Region cited flowing lessons she learned from the disaster:

- The arrival of flood was faster than expected. Flood warning and advise for evacuation to citizens were not as early as expected.
- There were not specific communication tools for disaster warning such as warning sirens. Municipal cars were used to inform local people of evacuation advice.
- There was confusion on communication between States and municipal governments. Towns could not receive appropriate enough information on the disaster from State.
- Relief goods arrived late, and distribution system was not ready to cope with them.
- Huge debris by floods overwhelmed local governments and people after the disaster.
- There is urgent need to educate mayors and local officials on disaster management.
- Coordination between State and local governments became smooth after an expert on disaster management was sent to the municipality by State Government.

These are common lessons in addressing water-related disasters irrespective economic and social status. Local-level readiness and support by state/federal governments are the key.

As water-related disasters may increase in numbers and severity due to many factors including climate change and urbanization, importance of sharing lessons of disasters should be recognized by all countries from top to field levels.

1.4 Continuation of COVID-19 in 2021 and two HELP principles to help countries to cope with the crisis

The year 2021 was marked by continuation of COVID-19 in a series of waves, which is in itself a major health disaster and in many senses related to water. It became one of the worst pandemics through history. As of September, 2022, global total number of infected cases is 650 million and that of death is over 6.5 million.

High-level Experts and Leaders panel on Water and Disasters (HELP) continued actions to help countries and stakeholders to address the unprecedented "twin pandemics". "HELP Principles to Address Water-related Disaster Risk Reduction under COVID-19" were translated into 16 languages including 6 UN official languages since its launch on May 31st, 2020, and helped DRR practitioners, medical people, and citizens to cope with co-occurring disasters and pandemic. As introduction of vaccines and medicines to combat the pandemic, and "building-back-better" from its devastation is of urgent political issue, HELP also launched "Guiding Principles to Build Resilient Post-Corona World - Towards building a more resilient and adaptive post-corona society" in order to help countries to recover impacts of COVID-19 and build more resilient, sustainable, and inclusive post-corona society.

Eighteen Presidents and Prime Ministers that gathered the 4th Asia Pacific Water Summit in Kumamoto, Japan in April, 2022 advocated for building back better to create more resilient, sustainable, and inclusive "quality-oriented society". Water-related Disaster Risk Reduction under COVID-19 was the focus of discussion in the Summit.

Major Water-related Disasters in 2021-2022

2. The July 2021 flood disaster in Germany

Kron, W., Bell, R., Thiebes, B. & Thieken, A.H.

Wolfgang Kron – Geo Risks Research, Munich Re (retired)
Rainer Bell – Department of Geography, University of Bonn
Benni Thiebes – German Committee for Disaster Reduction, Bonn
Annegret Thieken – Institute of Environmental Science and Geography, University of Potsdam

Summary

Various regions in Europe were hit by extreme rainfall from July 12 to 19, 2021 generated by a quasi-stationary atmospheric low pressure system named "Bernd". The mainly affected areas were two federal states in western Germany and adjacent regions in Belgium. The July flood was the costliest natural disaster in Germany in recent history, with losses in the order of 33 billion euros (USD 40 billion[1]). At least 189 people died, more than in any other flood in Germany in the past 50 years. Some narrow valleys in the Eifel mountain range were overwhelmed by torrential waters that arose within a span of just a few hours and reached levels never seen before. Extreme destruction due to the flooding, floating debris, bank erosion and deposition occurred. Local traffic infrastructure, power, gas, and water supply as well as the telecommunication networks were damaged and disrupted.

Although heavy and disastrous rainfall had been forecast by the weather services a few days ahead, the early warning process and evacuation did not work well. Warnings from the issuing agency did not reach many of the intended recipients in a timely manner and automated early warning systems were either unavailable or did not function properly. Hence, in some places, evacuation measures came too late or not at all. Additionally, many of those that received warning notifications underestimated the severity of the approaching event.

The relief and reconstruction process became a national task. Immediately after the waters had receded, thousands of first responders (most of them volunteers) from all over the country came to help to clean up in the area, and to provide residents with items needed. Recovery of the region is supported by federal funds and accompanied by newly set up research projects to ensure wise, sustainable, and resilient reconstruction of the destroyed valleys. Funding is being provided for infrastructural measures and also for assisting home- and business owners to get back on their feet. Less than half of them were insured.

1 The triggering weather event

1.1 Hydro-meteorological context[2]

May and June 2021 had already been rather wet in western Germany with 10-40% more precipitation than average. The soil moisture in much of the country was generally high. In particular in the southern half of Germany less than 10 mm (10 l/m^2) of pore volume was available for soil water storage (Fig. 1).

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[1] In this article, EUR is used as currency; for converting into USD multiply by 1.2.
[2] Most of the meteorological data and descriptions in this chapter were adapted from DWD 2021.

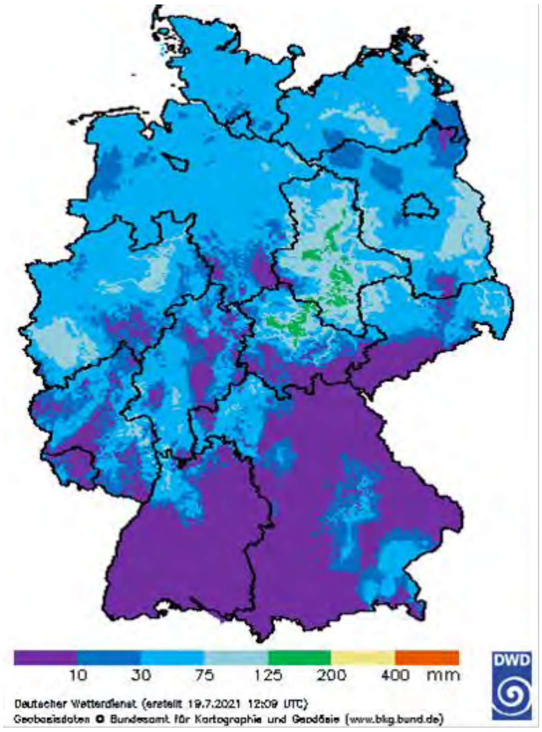

Figure 1: Available soil water storage in mm in the top 60 cm under grassland on July 12, 2021 (DWD 2021)

Before the July flood, a series of tempests on a path through the middle of the country from west to east involving thunderstorms, heavy rain, hail and lightning strikes during a 13-day period from June 18-30 already caused insured losses of EUR 1.7 billion – including about EUR 400 million due to floods (GDV 2021). This implies that the overall losses were probably in the order of EUR 3 billion.

Then, on July 12, an atmospheric low pressure system named "Bernd" started to pass across Central Europe. Its forward movement was very slow; at times it even remained stationary. This pressure situation sent warm, moist air from the northern Mediterranean via Slovenia and Austria to the Czech Republic and Poland, and eventually to northern Germany. In the evening of July 14, the temperature in western Germany was about 14 ºC, while northern Germany reported 30 ºC and thunderstorms. The very warm and moist air in the north was entrained into the low. At the same time cold air moved from France towards Germany. The mixing of these air masses led to extraordinary condensation processes and, due to the slow forward speed of "Bernd", to extreme rainfall amounts of more than 150 mm in 72 hours on a large area (Fig. 2). "Bernd" stayed active until July 19 and caused floods not only in Germany, but over large parts of Europe.

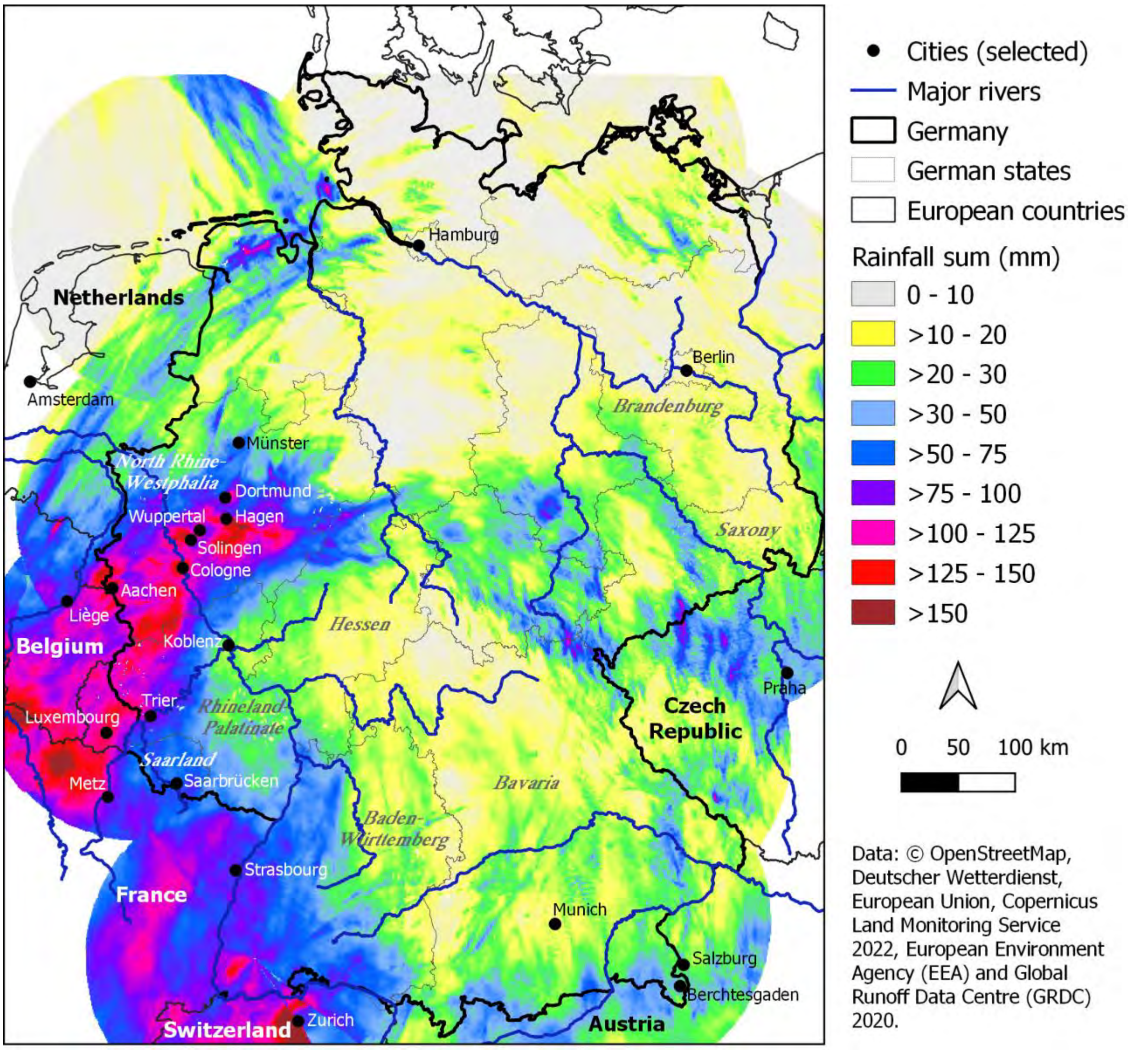

Figure 2: 72-hr-precipitation in Germany from 2021/7/12, 5:50 UTC to 2021/7/15, 5:50 UTC (processed by R. Bell from DWD RADOLAN data (combined radar and station-based data))

1.2 The affected areas

Various regions of Germany were affected successively from west to east by enduring and locally highly intense rainfall (Fig. 3). On July 12, southwestern Germany (parts of Baden-Württemberg, Hessen, Rhineland-Palatinate, Saarland, and North Rhine-Westphalia) received up to 50 mm of rainfall in 24 hours. On July 13, some central German regions (Ruhr area, northern Hessen, northern Bavaria and Saxony) were hit by rain with local intensities of more than 40 mm in 30 min, almost 90 mm in 2 hrs and regionally more than 150 mm in a day. In the city of Hagen, authorities measured 241 mm in 22 hrs. The rainfall occurred as sustained rain with episodic heavy rainfall periods embedded. Numerous villages, but also larger cities (such as Wuppertal, Hagen, Solingen, Cologne, Bonn, Düsseldorf) were subject to local heavy downpours and experienced major flooding.

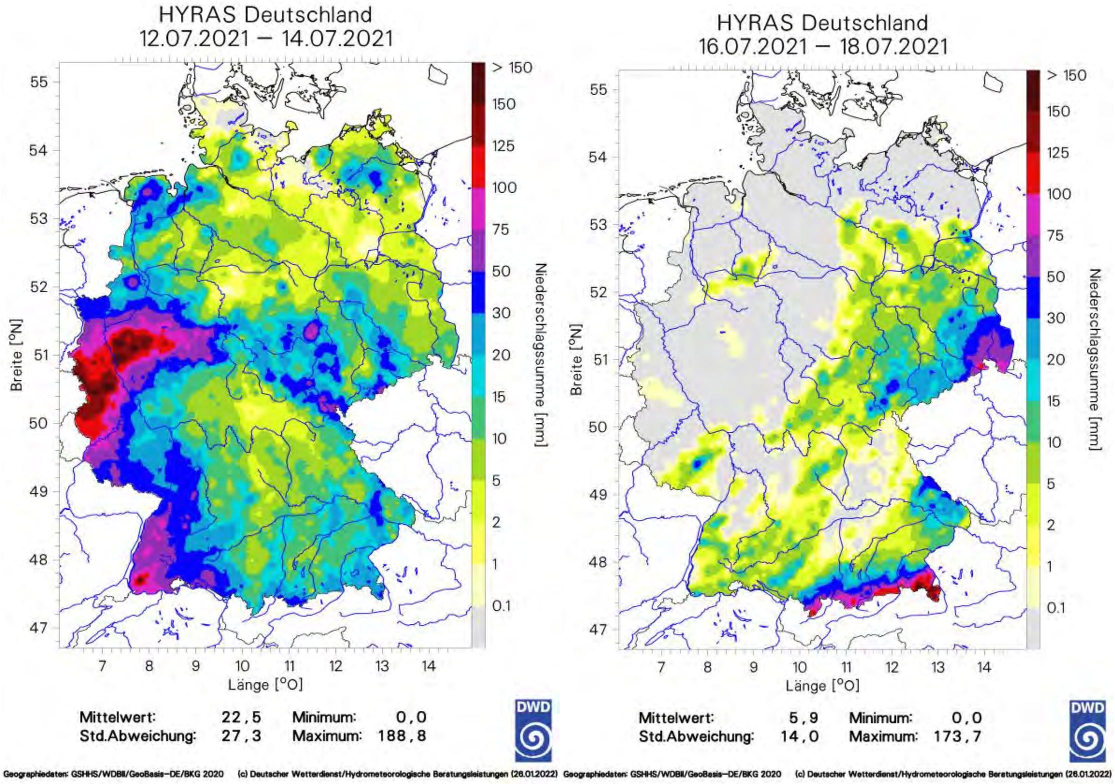

Figure 3: Rainfall analysis based on 72-hr hydro-meteorological raster data from July 12-14 (left) and July 16-18 (right) (DWD 2021)

The disaster in the west of Rhineland-Palatinate (RLP) and the southern half of North Rhine-Westphalia (NRW) began on July 14. Copious rainfall, time and again interrupted by high-intensity showers, hit an area centered by a line from Dortmund (north) via Cologne to Trier (south) (Fig. 4). More than 100 mm in 72 hrs were recorded over a large area, with regional peaks of over 150 mm in 24 hrs. July 14 was the wettest day in Cologne since measurements began 70 years ago.

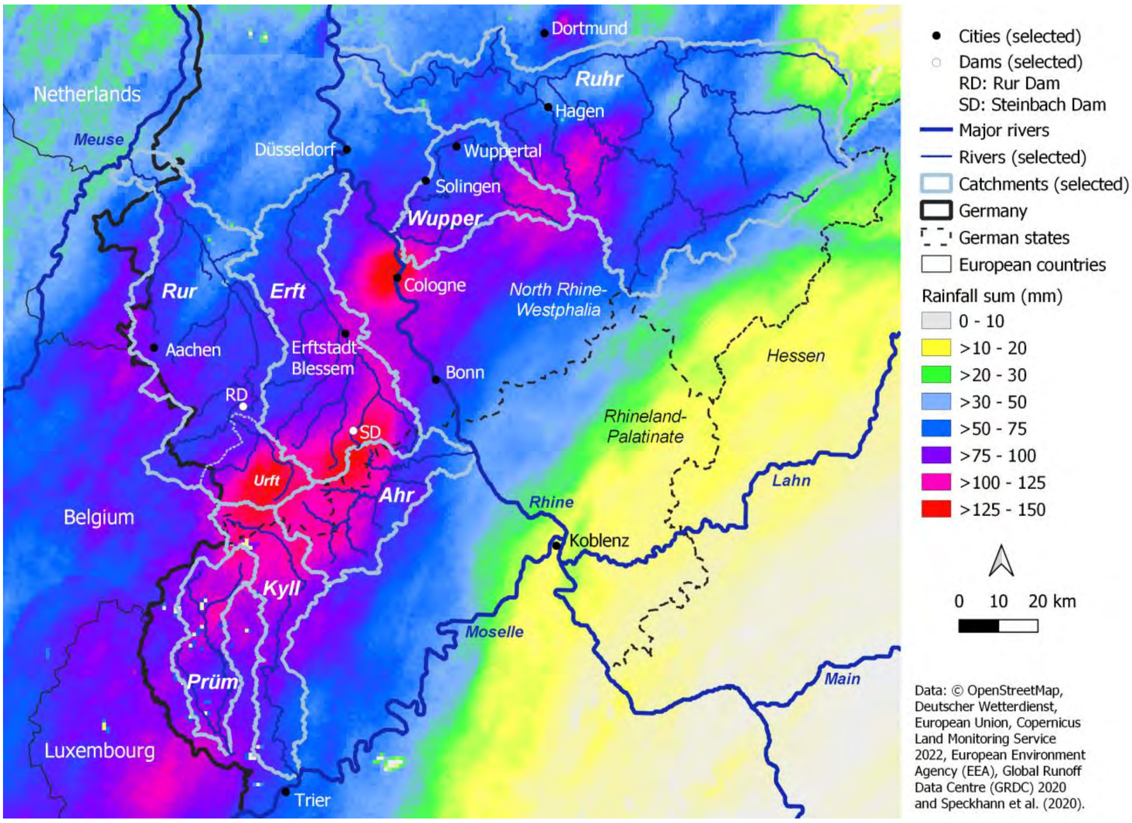

Figure 4: 24-hr precipitation in the disaster area of western Germany from 2021/7/14, 5:50 UTC to 2021/7/15, 5:50 UTC (processed by R. Bell from DWD RADOLAN data (combined radar and station-based data))

Whole catchments of the affected regions in RLP and NRW witnessed high rainfall depths. The rain hit an area with high soil moisture and largely exhausted retention capacity of the ground. Widespread surface runoff and sometimes even sheet flow was the consequence. Nevertheless, not even unsaturated soil could have infiltrated the enormous amounts of precipitation. The water was channeled in the often very narrow valleys of the rivers Ahr, Erft, Rur, Kyll, Prüm, Wupper, Ruhr and their tributaries (Fig. 4). Additionally, local flash floods happened without a larger watercourse being involved at all. Streams and rivers overtopped their banks almost everywhere. Massive erosion, scouring and undercutting of hillslopes, roads, railways, and buildings took place and trees fell. At many places, water stages were considerably increased after clogging of bridges. After the flood the government of RLP forbade to store firewood and other unfixed material in the open space. This precaution was meant to prevent sources of floating matter during a flood.

At Altenahr gage the water level in the Ahr river exceeded the stage of 9 m, more than 8 m higher than the normal value at mean flow of 7 m^3/s and more than 5 m higher than the officially estimated 100-year flood level at 241 m^3/s. As much as 10 m were actually observed in Altenahr, but this figure may be biased by the local hydraulic situation (e.g., sediment deposits or water backup).

While "Bernd" moved on in southeasterly direction from July 15 to 19, it charged eastern Saxony and southeastern Bavaria with another heavy rainfall load (Fig. 3 right). Again, orographic effects (at the Ore Mountains, Lausitz Mountains, and the European Alps) enhanced the intensities through relief effects. Numerous flash floods and short extreme flood waves in some medium-sized rivers occurred.

Altogether, the low pressure system “Bernd” brought exceptional rainfalls in large parts of western, central and eastern Europe (Fig. 5) that led to floods and losses in the United Kingdom (esp. London), France, Switzerland, the Benelux countries, the Czech Republic, Austria, Italy, Poland, Slovakia, Hungary, the northern Balkan countries, Romania and Bulgaria, but – except for Belgium – the consequences were far less than in RLP and NRW.

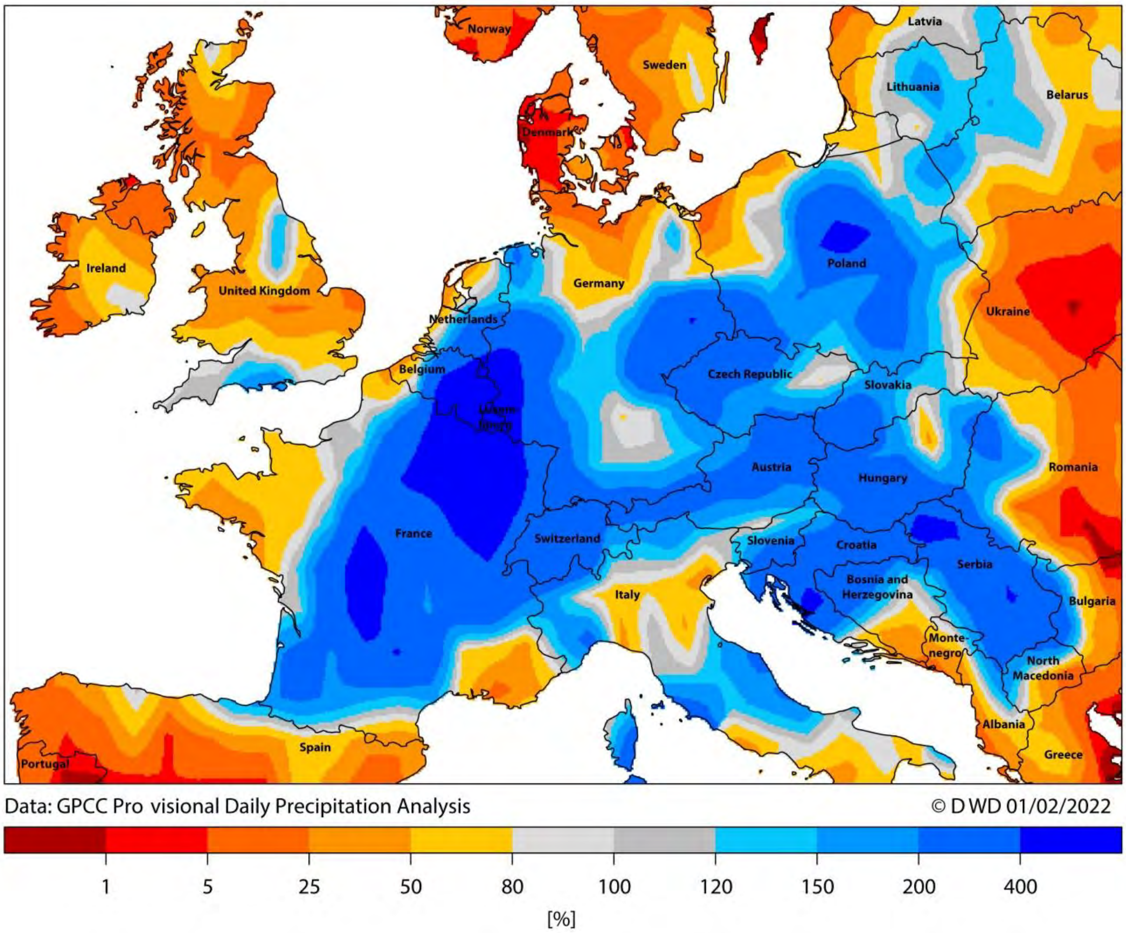

Figure 5: Accumulated rainfall in the week of July 11-17, 2021 in Europe as percentage of 1982-2010 averages (DWD 2021)

1.3 Climatological context

The average 72-hr areal rainfall of 127 mm from July 12 to 14 in the six catchments of Ahr, Erft, Rur, Prüm, Kyll, and Wupper was about 170% of the 1991-2020 July average total rainfall depth, and in the Ruhr catchment it was 104%. The daily station rainfall depths between 80 and 120 mm in the Eifel mountains south of Cologne corresponded roughly to 100-year daily rainfall events. But the analysis of a 30-year precipitation dataset for the two catchments of Ahr and Erft rivers (see Fig. 4) resulted in a 24-hr areal average of 93 mm, a value that frequency analysis associates to a return period in the order of 15,000 years. This indicates how extreme the event was. Nevertheless, no all-time German rainfall record was broken in 2021, but previous highs were exceeded at an unusually high number of weather stations in the west of the country.

Point rainfall of 150 mm in 24 hrs is not rare in Germany. Just two weeks earlier, on June 30, around 300 mm had fallen in three districts of northeastern Brandenburg, twice the amount. However, Brandenburg is flat and has sandy soils with high infiltration capacity, so that rain caused significant, but not disastrous damage. Had that weather system poured its water on the Eifel mountains instead on Brandenburg we would have seen an even more catastrophic event there. The DWD classifies warnings from heavy rainfall based on threshold values, separately for short durations (1 to 6 hours) and long durations (12 to 72 hours) (Tab. 1).

Table 1: Definitions of the German Weather Service (DWD) for "Heavy rainfall" (DWD 2022); warning is classified in three levels defined by threshold values

		Heavy rainfall	Sustained rainfall	
Warning level	**Description**	**Threshold for precipitation**		**Presentation**
1	significant weather possible (stay informed)	< 15 mm in 1 hr < 20 mm in 6 hrs	< 25 mm in 12 hrs < 30 mm in 24 hrs < 40 mm in 48 hrs < 60 mm in 72 hrs	
2	significant weather	15 to 25 mm in 1 hr 20 to 35 mm in 6 hrs	25 to 40 mm in 12 hrs 30 to 50 mm in 24 hrs 40 to 60 mm in 48 hrs 60 to 90 mm in 72 hrs	orange
3	tempest	25 to 40 mm in 1 hr 35 to 60 mm in 6 hrs	40 to 70 mm in 12 hrs 50 to 80 mm in 24 hrs 60 to 90 mm in 48 hrs 90 to 120 mm in 72 hrs	red
4	extreme tempest	> 40 mm in 1 hr > 60 mm in 6 hrs	> 70 mm in 12 hrs > 80 mm in 24 hrs > 90 mm in 48 hrs > 120 mm in 72 hrs	purple

However, areal rainfall with a depth of more than 100 mm in 24 to 48 hours over a larger area is rare in Germany. Normally local floods follow. The July 2021 rainfall intensity varied significantly over time. At the beginning, only short extreme events of one to six hours were observed. In the following, a mixture of repeating events (i.e., those with interrupted rainfall) and sustained events (i.e., uninterrupted rain) was observed. This led to very high rainfall depths in the 9 to 48 hour time spans. Most of the occurrences in this first phase of the low were classified as 100-year – and often even much rarer – events in central and western Germany.

As early as July, the year 2021 ranked already among the top five years with regard to number of heavy rainfall events in Germany since 2000. Typically, most intense rainfalls are observed in May and September. Although heavy rain may occur anywhere in Germany, extreme events with long duration (9 to 72 hours) are typical for the medium and high mountain areas.

1.4 The role of climate change

The average temperature in Germany has increased even more (about 1.6 K) than the global average (1.2 K) since the late 19th century. Low "Bernd" was possibly a harbinger of what may have to be expected with a higher frequency in future. However, it was probably not so much the fact that warmer air can hold – and thus release – more moisture, but the effect of higher temperatures on the global atmospheric circulation patterns that played a role in the flood event.

The polar jet stream has clearly changed its characteristics in the past decade. It slows down at times and its path develops undulations reaching as far south as Central Europe. Their bulges can trap highs and lows, which thus become quasi-stationary and cause either extremely wet, or extremely dry and hot periods in a large area over several weeks. Numerous weather-related disasters in the past two decades can be attributed to such behavior of the jet stream, the most striking maybe in 2010, when western Russia experienced a record heat and wildfire season while lying in an atmospheric high-pressure area, and at the same time Pakistan suffered from disastrous rains that lead to the Indus flood (Hoffmann et al. 2021).

According to an analysis of daily rainfall data of the past 70 years, the German Weather Service found that frequency and intensity of heavy rainfall events (>20 mm/d) have increased slightly in Germany, although the overall number of rainy days has decreased. The Intergovernmental Panel on Climate Change (IPCC) made a similar statement in its recent report on the up-to-date physical understanding of the climate system and climate change (IPCC 2021). However, there is still no statistical significance that weather systems prevail longer over a certain region due to climate change. It is agreed that natural variability will still dominate in the decades to come. Where, when and how severe extreme events happen, and where disasters strike will continue to depend mainly on the actual situation and local conditions.

The underlying factor of "Bernd" was exactly that lingering of a bulge of the jet stream. The low stalled and thus could drop huge amounts of rainfall on a particular area. The events were analyzed by 39 researchers of the World Weather Attribution Initiative. They found that the likelihood of extreme rainfall events like the July floods to happen anywhere in western Europe due to climate change has increased by a factor of 1.2 to 9. This analysis also showed that the rainfall intensity in this region has increased between 3 and 19% due to anthropogenic climate change (Kreienkamp et al. 2021).

2 The flood disaster

2.1 Discharges and stages

The bedrock in the Eifel mountains mainly consists of shale rock, which impedes percolation and makes the underground almost impermeable. The upper catchments of the rivers have rolling to flat slopes; their valleys have densely built-up narrow floors and steep sides, mostly covered with vineyards without ground cover. These little structured and thus "hydraulically smooth" surfaces offer hardly any flow resistance and accelerate the runoff.

The orographic characteristics, absence of retention areas, impervious urban surfaces and dense settlements were major factors for the flood combined with the wet soil conditions and the enormous amount of rainfall. Especially the Ahr valley was outstanding with respect to discharges, water levels and human and material losses. With 89 km the river is not the longest in the area nor has it the largest catchment (900 km^2); but it was almost entirely within the center of precipitation (c.f. Fig. 4).

The river's discharge, normally less than 10 m^3/s, shot up to an estimated 700 to 1200 m^3/s within a few hours, with the stage at Altenahr gage (Fig. 6) increasing from 1 m to more than 9 m. When it reached 5 m, the gaging station was destroyed, so the actual peak could only be estimated. The highest measured historical value (on June 2, 2016), which was believed to be a 100-year flood at the time, had been 236 m^3/s with a gage level of 3.71 m. The return period of the 2021 Ahr event is estimated to exceed 500 years – maybe by far.

Figure 6: Location of towns in the valley of the Ahr river

Flood hazard maps for the Ahr valley valid for July 2021 are based on complete homogeneous flow records since 1947. When creating the maps, historic extreme events were not taken into account as is state-of-the-art in Germany; therefore the 100-year discharge value at gage Altenahr was "only" 241 m^3/s. A recent, new frequency analysis that takes into account historical values since 1804 resulted in a return period of only around 30 years for the 2016 discharge, not 100 years. This analysis also showed that most of the annual maxima included in extreme value statistics came from winter floods while extreme events in the summer were rare – but these were the highest.

2.2 Historical context

The event in July 2021 was immediately called an "unprecedented" flood and one that has "not been seen in a lifetime". That was both true and wrong. It certainly was not the first extreme flood in the Ahr valley. Besides the mentioned – lower – 2016 event there were historical reports about comparable extreme floods in 1804 and 1910 with 63 and 52 deaths, respectively.

Figure 7 shows a house in Walporzheim (9 km downstream of Altenahr and 16 km upstream of where the Ahr joins the Rhine river) with three water marks. The water level in July 2021 was about 3.5 m higher than the one in 1910. However, comparing just the flood marks does not allow a proper estimation of the 2021 discharge.

Figure 7: Water marks in Walporzheim: The 1910 mark is about 50 cm above the ground level; the 1804 mark is 1.7 m higher and the 2021 mark 3.5 m higher than the flood level in 1910. The 1804 flood is remembered by an inscription "*Ten 21 Julius a(nno) 1804 hat tie ar gestanten so hoch alhir Emmericus Lejihs" - "(On) the 21 July 1804 has the Ahr stood so high here. Emmericus Lejihs (owner)*". 1910 is remembered by "Hochwasserstand (flood level) 13.06.1910" (Photo A. Fekete)

In the past 100 years many changes took place in the valley, from redesigning the river bed and building bridges to filling the valley floor with buildings. The latter two, in particular, may have had a large influence on the stages. Most bridges were clogged during the event by dead wood, uprooted trees, and debris with the consequence of backed up water and therefore higher water levels (Fig. 8). Similarly, more buildings than in 1910 and 1804 stood in the path the flow requires during extreme discharges. They introduced higher flow resistance and may even have created backup effects. Next to the sedimentation of debris and mud, it is thus very likely that this was a reason for the significantly higher water levels in 2021 (assuming that the discharges were not very different from 1804).

Figure 8: Accumulation of debris at a bridge near Altenahr (DLR 2021)

Roggenkamp & Herget (2014) estimated the discharges at Walporzheim for the two events in 1804 and 1910 at 1180 and 540 m^3/s, respectively. The 2021 discharge was somewhere between these two floods. A rainfall-runoff model calibrated to the region and driven with the observed rainfall resulted in a discharge of 850 m^3/s at gauge Altenahr (pers. comm. Flood Forecasting Center of Rhineland-Palatinate on 10 Feb 2022). It is noteworthy that the time period between the three events was approximately the same: around 110 years.

Flood management and, in particular, the influence of reservoirs was very distinct. Significant differences between catchments with and without major dams became evident. In contrast to the Ahr and Erft catchments, that have almost no reservoirs – at least no reservoirs of significant size but only a few small ones without a function of flood retention – the Rur catchment has a complex system of dams. While upstream of the Rur Dam, in the catchment of the river Urft (the area where the highest rainfall amounts occurred) flooding was extreme and caused 15 fatalities in various villages, the discharge downstream of the Rur Dam was lower than the highest value recorded in history. Hence, a lot of damage was prevented by the dam.

In northern and central NRW where numerous large reservoirs systems exist mainly for drinking water supply (e.g., along the rivers Ruhr and Wupper) dams played a considerable role in mitigating the flood crests. The hard-hit Wupper system with its 14 dams escaped a disaster although many settlements suffered flooding.

Practically all reservoirs were full and eventually their spillways were in operation. The discharges were in some instances twice the design flood, which is, in the case of designing a large dam, a 10,000-year event. Despite the large inflows, all dams survived the flood without notable damage even though some of them were more than 100 years old. Severe damage was only experienced at a few small, detached dams.

2.3 Consequences and losses

The July floods caused chaos, destruction and grief at many places, killed and injured people and left others in shock (Fig. 9). In total, presumably 189 people lost their lives in the context with the floods in Germany. 135 died in RPL and 49 in NRW, five in other Federal states. Additionally two men are still missing. One firewoman in RLP and three firemen in NRW died on duty. Unfortunately, there were also reports of at least four suicides in the aftermath of the event. Exact figures of victims in a natural disaster are sometimes difficult to state as a causal relation to the natural phenomenon is not always certain – for instance if death is caused by heart attack or accident.

Around 770 people were injured in RLP alone, and thousands traumatized. In the Ahrweiler district of RLP, 134 people fell victim to the disaster. Most of them (106) were elderly people over 60 years; three children younger than 14 years died (DKKV 2022). The proportion of females (70) to males (65) was balanced – a pattern that was also observed in Europe in the context with storm surges along the North Sea coast, in 1953 in the Netherlands and in 1962 in the city of Hamburg. In NRW, 25 cities and districts were affected by the floods. Among the 49 fatalities in NRW, 31 were male and 18 female showing the more typical gender pattern of flood fatalities in Europe, the USA, and Australia with a clear overrepresentation of men. Again, elderly people were hit more often than suggested by their share in the overall population: 32 out of the 49 victims were older than 60 years revealing their particular vulnerability; many of them had pre-existing illnesses or were restricted in their mobility.

Figure 9: Bad Neuenahr: the flood came suddenly and with high speed and power at night; people had only minutes to save their lives; some drowned at the attempt to save goods (Photo J. Bogardi)

Firefighters, the German Federal Agency for Technical Relief (THW), the German Red Cross and various other relief organizations – all of them mostly consisting of volunteers –, the police and even the Armed Forces with their heavy clearing equipment took part in the immediate and mid-term relief operations. Additionally, a multitude of untrained volunteer helpers traveled to the affected areas and offered their help, either as human workforce or by bringing and distributing food, drinks, crucial items of daily need (such as hygiene articles), clothes, furniture, etc. Even at the beginning of 2022 there were still volunteers on the site from all over Germany.

The extent of damage to the residential sector may be up to EUR 15 billion. Much of the total estimated loss of EUR

33 billion comes from a large-scale destruction of infrastructure. In the Ahr valley, 103 road bridges were destroyed or heavily damaged. Statewide (RLP), 106 km of local, regional, and national roads, 115 km of railway tracks, and seven railroad bridges were scoured, destroyed or damaged, and therefore not usable anymore. In the district capital, Bad Neuenahr-Ahrweiler, which is divided into two parts by the Ahr, 13 out of 15 bridges disappeared (Fig. 10). It may result in major problems if the fire station, the police department or the only hospital is located on the other side of the river. Numerous components of services such as wastewater treatment plants, water, gas, and power systems were disrupted, 17 schools were heavily damaged, and 19 nursing homes had to be evacuated. Six hospitals and two rehabilitation centers were flooded; one hospital will remain closed for good. In a clinic, critical and expensive equipment is often found in the basement. A total loss of power forced the clinical staff in the city of Eschweiler to carry 300 patients through the staircase during evacuation, thus putting them to risk. Hundreds of doctor's practices were affected; many of them had to be closed for weeks on end, some for good. More than 330 people had to be rescued by helicopters from the roofs of their houses or from trees.

Figure 10: Destroyed bridge in Sinzig (Photo Peter. Ruland)

Right after the flood up to 165,000 people lacked electric energy, drinking water, and mobile phone services. Leaking gas pipes were hindering relief operations. The 100 year old, 17 m high Steinbach dam (see Fig. 4) overtopped and was about to burst and send a deadly surge to a downstream town. Catastrophic breaching could be prevented by the brave action of an operator who removed sediment from the blocked outlet of the dam with his excavator, and secured the structure.

Huge erosion took place along the watercourses, with the most dramatic incident in Erftstadt-Blessem, where the Erft river left its bed and flooded a gravel pit. The heavy backward erosion caused eight buildings to fall into the pit or to be undermined beyond repair; fortunately no one died here directly, but the picture of this site became one of the symbols of the floods' fury. In addition, traffic was heavily disrupted, because a motorway had to be closed leading to one deadly car crash right after the flood. Another deadly injury occurred later in August, when a school student was hit by a car in the high volume of traffic on a detour through Erftstadt-Blessem.

The order to leave came (too) late in some instances. An estimated 42,000 people living in the Ahr valley were affected and 17,000 of them suffered from massive losses. In the entire state of RLP, the number of affected was 65,000. About 8,800 buildings along the Ahr river were damaged (DKKV 2022); almost 200 homes and 275 other buildings were completely destroyed or had to be demolished. A vast number of cars sank in water or were flushed away. The Ahr valley is one of Germany's prime wine-producing regions. About 60 of the 563 hectares of vineyards were damaged or even devastated.

Public property and assets apart from infrastructure were also severely hit. In hospitals, air conditioning in operating rooms failed, churches and graveyards were eroded, undermined and devastated, and of course, city halls and other buildings that held important documents were flooded. People who lost personal documents in their flooded home could not be helped because many official files and electronic data backups disintegrated in flood waters. In Bad Neuenahr-Ahrweiler, about a third of the public administration's staff was personally affected by the flood and at the same time badly needed for helping the city's residents in their despair.

While data from 2021 are not yet available, a comparison of the average damage ratio of houses in Germany's 2013 river flood and 2016 flash floods, whose dynamics are comparable to the flood in July 2021, revealed that the ratios are considerably lower in the first case (2013: 9% for buildings, 19% for contents) than in the latter (2016: 21% for buildings, 39% for contents) (Thieken et al. 2022).

2.4 Specific cases

The region is generally very popular with tourists. Numerous campgrounds are located along the Ahr river and some of its tributaries. Several of the sites were upstream of the first gaging station, which posed a problem if early warning relied on observed measurements. At least one campground was devastated; seven people died in this incident.

The most tragic incident happened in the town of Sinzig (Fig. 6). The ground floor of the "Lebenshilfehaus (Live-aid house)", a home for 36 disabled people located almost 300 m away from the Ahr river (but within the official extreme flood zone!) was flooded within a few minutes. Twelve residents who were not able to go to the second floor by themselves died. A formal investigation was started on which warnings had been issued and in which way they were put into operation.

In Germany, a number of people heat their homes using wood pellets. These pellets are often stored in the basements of the houses or in annexes. Wood pellets increase in volume if they get in contact with water. There are reports that even 24 cm thick brick walls burst under the pressure of swollen pellet storages so that buildings became unstable and had to be demolished. Additionally, the pellet mass – that normally has a gravel-like behavior – turns into a monolithic concrete-like block.

In NRW, flooded heating systems released in one case a poisoning amount of CO_2, which intoxicated two individuals that worked in the basement; they fell into the water and drowned. In another town, a flooded oil heating caught fire killing two people. These cases emphasize the need of flood-adapted heating systems in flood-prone areas, let alone pollution problems due to oil spills.

Another spectacular incident was the flooding of the lignite pit Inden in the Rur catchment. The banks of the small Inde river were breached and water flowed into the pit, creating a canyon with a size of 4.5 hectares on its way, and killing a caterpillar operator.

In the utmost southeastern part of Bavaria around Berchtesgaden flash floods and landslides following massive short-term downpours (one to three hours) caused considerable local damage and destroyed the world-famous bobsleigh, luge, and skeleton track.

2.5 "Bernd's" place in statistics

"Bernd" produced the fifth billion-euro (flood) loss event in the 21st century in Germany, after 2002, 2010, 2013, and 2016 (Fig. 11). But none of previous three caused as many fatalities, injured, and overall losses as the 2021 floods. The latest estimation is EUR 33 billion (as of Jan 10, 2022) (Munich Re 2022). Up to EUR 20 billion – of which 75% was not insured – were incurred in RLP (DKKV 2022). Only one natural disaster – excluding heat waves and cold spells – caused more deaths in Germany since 1900: the Hamburg storm surge of February 1962 when at least 347 people died.

Europe-wide, "Bernd" probably claimed 240 lives (deaths and missing): 191 in Germany, 38 in Belgium, one in Austria. Belgium reported an estimated insured loss of EUR 2.164 billion (RTBF 2021) suggesting that overall losses of at least two to four times that amount have to be expected there. Adding the loss figures from all other affected countries the overall amount from the July floods yields EUR 46 billion (Munich Re 2022).

Fig. 11 shows the sequence of annual flood losses in Germany from 1980 to 2021. Here, a distinction is made between "pure" floods and floods in the context of severe convective storms (SCS). Such storms in most cases not only cause flooding, but also losses by wind gusts and hailstorm that cannot usually be separated. A rule-of-thumb assumption is to associate 50% of the total losses to flooding. While pure floods exhibit a large volatility but no distinct trend over the shown period, the SCS-related losses clearly increase.

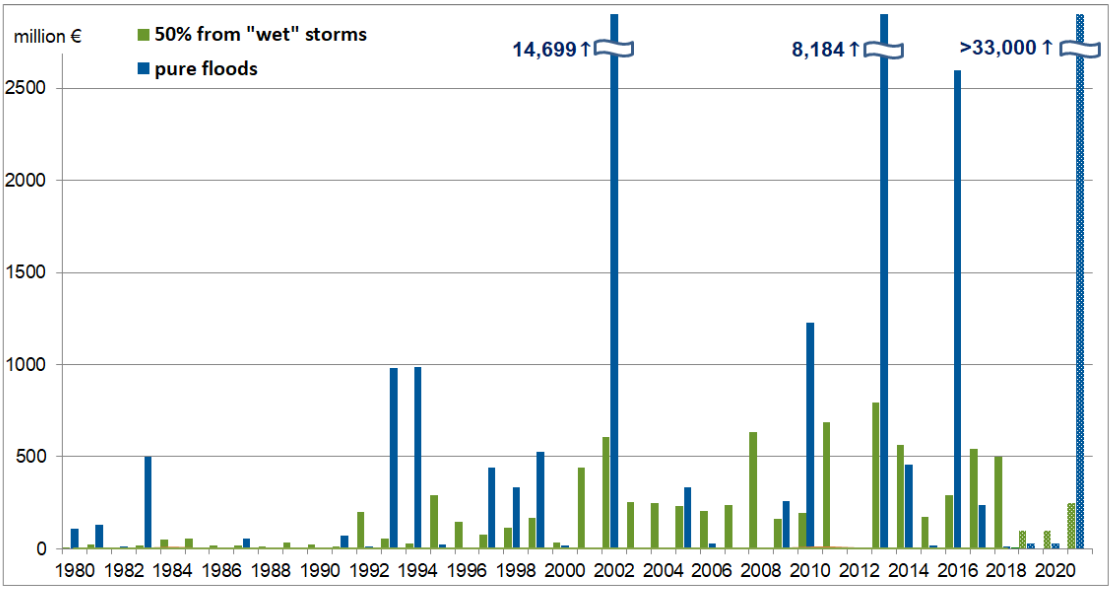

Figure 11: Overall annual losses (in values of 2018) from pure flood events and estimated losses from floods

during severe convective storms in Germany 1980 - 2021 (Kron et al. 2019 revised, losses 2019-2021 are estimated)

It seems that after large river floods in 1993, 1995 (Rhine), and 2002, 2013 (Elbe, Danube) expensive flash floods (i.e., due to short-term intense rainfall) have become more and more important as far as billion-euro losses are concerned. In 2010, eastern Saxony suffered losses of over a billion euros, and in 2016 losses in two regions in southern Germany added up to EUR 2.5 billion. The 2021 EUR 33 billion bill was the third in this series.

However, one must also not forget that the bulk (two thirds) of the EUR 11.6 billion loss amount in 2002 (original value) was created by flash floods in the Ore Mountains in Saxony – by rainfall very similar to the one in the Ahr-Erft region. So the phenomenon of expensive flash floods is actually not new, but just not present in the general public awareness.

3 Disaster response

3.1 Weather forecast and early warning in Germany

In Germany, warning from precarious weather events, including potentially severe rainfall and flooding of areas not bound to watercourses, belongs to the task of the national German Weather Service (DWD), while flood forecasting and warning is legally the task of the federal states.

As soon as a severe weather event is identified, official warning situation reports are published up to 48 hours ahead of its occurrence; initial reports are issued even five days before in "weather warnings". These reports describe the expected development of the weather situation during the following 24 hours based on numerical simulations. Early warning of rain bursts is difficult though as this type of event is normally produced by dynamic convective storm cells, which are often local and small-scale. Although numerical models are high-performance tools nowadays, the challenge to come up with accurate values for time, location, and intensity of heavy rainfall is often too great. The models are only capable of issuing forecasts within certain ranges for these three parameters.

River flood forecasts are made by the flood control centers of the 16 federal states, based on DWD weather forecasts. Hydrological and hydraulic models exist for the major rivers and their main tributaries, but forecasts are also available for many mid-size and even smaller rivers at their gaging stations. The expected flow development within the next hours is accessible on the internet (operated by the flood control center of each state) for practically each state-operated gaging station.

3.2 Warning procedures

In the anticipation of a potentially disastrous event it is particularly important to inform and warn the exposed population as well as the sectors involved in disaster management (authorities, disaster relief units, etc.) quickly and specifically. Precise early warning is one of most effective measures to save lives. Authorities and security organizations decide about the content of the messages and the time of issuing. The tools used by the federal government and the states to warn the general public are: public broadcasting (radio and TV), mobile phone apps, sirens, and vehicles with loudspeakers. Additionally, there are official warning paths to authorities and specific stakeholders. Instantaneous information, i.e., the notification of an imminent or already ongoing occurrence is essential in the case of disaster.

Early warning procedures from weather and flood events were modified after 2002 when the DWD introduced an additional purple warning level 4 for extreme, potentially life-threatening events. Improvements were also made concerning the cooperation between the different public services (DWD, flood control centers, disaster relief agencies) and operational procedures were harmonized. Nevertheless, the organization of flood forecasting and warning might still differ between federal states.

There are several apps for distributing warning information to the population in Germany. One is NINA (Emergency Information and News App) of the Federal Office for Civil Protection and Disaster Assistance (BBK), another WarnWetter (WarnWeather) of the DWD. Katwarn is an app operated by the Fraunhofer Institute for Open Communication Systems (Fraunhofer 2022) that provides warnings and recommended actions to users in their respective areas. There are also apps run by insurance companies. Warning messages by official institutions (e.g., BBK, DWD, local fire brigades) are distributed by MoWaS, a multi-path warning system run by the BBK (BBK 2022). Both NINA and Katwarn display those messages.

3.3 Forecasting and early warning in the July 2021 floods

The event of July 2021 was generally well captured by the forecasting and warning system. The DWD and other private weather service providers had warned of heavy precipitation quite early and the potentially affected districts issued 150 warnings on BBK's MoWaS via apps and via the media. The State Office for the Environment in RLP issued a flood warning at 3:30 pm on July 14. The forecast value of the water level for the Altenahr/Ahr gage (5.19 m) was much higher than the highest recorded water level (3.71 m in 2016) and resulted in the highest warning level. It was transmitted just after 5 pm via the warning apps and other media. Although an intermediate forecast that came up with a lower figure (about 4 m) – caused by the failure of a gage and the fact that the DWD had lowered the precipitation to be expected – the high warning level continued. The following forecast stages were 5.30 m at 8 pm, 6.81 m at 9:30 pm, and 7 m at 10:25 pm. Eventually the water level exceeded 9 m in the early morning of July 15 (Kirschstein 2022).

4 Lessons learnt for disaster management

4.1 Disrupted warning paths and individual behavior

Despite the timely knowledge of outstanding rainfall to come and carrying out the usual preparation measures, both authorities and people in the area did not imagine the height and the speed of the flood wave that was ahead.

There were severe problems in the early warning chain in RLP and NRW. Forecasts and warnings had been issued by the authorities in charge, but the chain of information was interrupted and the warning got stuck on the way to the people. It seemed that both individual wrong decisions and procedural deficiencies were to blame for these incidents. They became cases for investigation by prosecutors and parliamentary committees.

In many cases the alert did not reach the people concerned, because warning systems did not function properly or had been dismounted as in the case of sirens. Warnings via smartphones could reach only those who had installed the respective app. Many people had turned off their smartphones at night and in some areas the power and the mobile phone networks were immediately disrupted due to the flooding. Also, the warnings were not completely different from that one week earlier when “normal” heavy rain and tempest events had been predicted. Hence, a certain fatigue effect in taking notice of such messages can be assumed.

Providing automatic gage statuses, stage predictions, and warnings are helpful, but they often fall short to informing their target subjects appropriately in extreme cases. To express it vividly: they “do not shout to the addressees with an emphatic voice”. Even a blinking red dot on the display does not compare to a human-to-human call that informs the crucial agents such as police, flood fighters, and disaster managers about the seriousness of the situation. In the Ahr region there had been several tempest warnings during the two weeks preceding the disaster, some of them with the highest (red) level. This inflation of warnings is counter-productive with regard to efficiency. What is missing is an upset voice: “Get your people out! Now and at once!”.

The mere height of the flood wave was foreseen by no one, neither by the experts nor by the population; it arrived as a big surprise. There were some doubts among disaster managers that the forecast values were credible. Hence, they did not order evacuations or hesitated to do so in some cases, presumably because the declaration of the state of emergency also involves costs to be borne by the districts. Additionally, some local authorities neglected (or forgot about) the existence of flood hazard and risk maps when they chose areas to be evacuated. It has to be acknowledged that evacuations in some places were based on the hazard maps for an extreme flooding, but the real flood extent surpassed the mapped areas.

Of the 189 people who lost their lives in Germany, 134 died in the Ahr valley. More than half of these fatalities occurred in Bad Neuenahr-Ahrweiler. It is not possible to associate all deaths to specific causes (e.g., no or too late warning, attempts to save items from flooded lower parts of houses, etc.), but the particularly tragic case of the twelve fatalities in the Lebenshilfe House in Sinzig (see section 2.4) is clearly a consequence of failing to evacuate the residence.

A poll drawn by Thieken (University of Potsdam) found that 29% (in RLP) and 35% (in NRW) of the flood-affected people reported “I wasn’t warned or I didn’t become aware of the upcoming flooding”. These figures fit well into results from earlier polls after flash floods in Germany that range – with few exceptions – from about 25% to 40%. With regard to river floods only, the warning system performs much better leaving just 5% of the affected population without warning (in June 2013). In July 2021, around half of the people (48%) strongly believed in the warnings, but just a mere 15% expected the situation to become very severe. The share of respondents in the poll who were warned but did not know what to do to protect their lives and properties was 41% (RPL) and 51% (NRW), which is also quite typical for flash floods in Germany. This lack of knowledge and awareness clearly shows that the biggest challenge is reaching the minds of the people, not optimizing technical systems and the early warning chain. Risk communication with regard to pluvial and flash floods is underdeveloped in comparison to risk communication about typical river floods.

One individual that lived in a home near a small tributary of the Ahr had been evacuated but returned to rescue a dog and drowned in the basement of the home after the fire brigades had to retreat due to the rising waters. Such cases when people act in panic or without judging their own risk properly are often reported after floods. Rescuing pets or cars is a frequent cause for death.

4.2 Lessons learnt and lessons to learn

Until the 1990s practically every commune in Germany had a siren. When the Cold-War era ended the necessity to warn from air attacks was not thought to exist anymore and as, at the same time, communication devices to alert fire brigades (e.g., beepers, cell phones) became available, the sirens were dismounted in most places. This has been criticized by the disaster reduction community for many years. Sirens are reliable and robust means of warning and at least an important additional method to convey a message. Information via mobile devices such as cell phones is only possible if mobile and power systems are intact. It is crucial not to rely on only one tool, but use a set of them tailored to specific addressees and situations. If a crisis is imminent or ongoing, digital communication alone is insufficient. Power (including that feeding cell towers) may not be on, while sirens can be back-up powered by batteries. Fire trucks and police cars with loudspeakers are also an option (provided routes are passable), and one should not forget the possibility of ringing church bells.

Another method of warning the civil sector is cell broadcast, i.e., all mobile phones in the area concerned automatically receive a text message. This method is – other than in some other countries such as the Netherlands, Italy, and the USA – not yet available in Germany. As one consequence of the floods, the federal parliament decided a few weeks afterwards to implement cell broadcast.

A crucial aspect in warnings is to complement the alert with specific instructions what to do (or not to do) and how to behave. Warning apps generally remain on the level of pre-formulated statements and lack recommendations tailored to the upcoming event and the addressed audience. A smartphone weather app provides a set of figures and maybe a standardized wording of a warning. In contrast to that, an expert on TV interprets these figures and tells people what they have to expect and what they should do. Also, a distinction must be made between (well) before an event and during the event. During the event detailed information needs to be spread on specific local situations, such as impassable roads, safe gathering places (and how to get there), imminent specific threats, and so on.

The general lack of preparation (including negligent or no protection measures) reflects low risk awareness with respect to extreme weather events – both by individuals and communities. This calls for a different, localized risk perception. The typically small-scale flash flood events that happen away from the own living area do not create enough awareness even though news from places hit are heard, but not thought to be a possibility at one's own location. People are therefore reluctant to undertake precautionary measures. However, in the light of an imminent extreme event, long-established residents may tend to believe they have everything under control, whereas people who have moved there may feel uncertain and be more careful. In order to counteract this attitude, it is necessary to rethink and establish a positive risk culture. The general public must get better used to early warning as part of efficient disaster management in future. Introducing "warning days" and frequent exercises in preparation for the disaster case in the civil and educational sectors as well as in enterprises is essential.

5 Preparedness, protection and structural issues

5.1 How did existing systems perform?

Flood protection along the relatively small rivers of the Eifel mountains is little pronounced. In most places there are no dikes or flood walls. Where structural protection is found, its height is rarely salient in the landscape. Retention along the rivers is also almost not existent due to very limited space in the narrow valleys. Only in the headwaters of the Ahr and Erft catchments a few small reservoirs designed for flood detention are found.

Material consequences from significant floods are mainly determined by 1) the existing values at risk and their vulnerabilities, and 2) by the possibilities of how flood waters can be controlled. The latter comprises everything that can influence the runoff and streamflow: land management, natural retention, drainage systems, river training, reservoirs, dikes, flood walls, flood bypaths, etc. In this field, various deficiencies and mistakes made in the last centuries were recognized and corrected in recent years, in particular in the aftermath of the large flood events in 2002 and 2013. The trend of the negative influence on losses caused by the development of residential, commercial, and industrial areas at risky places, however, has been unbroken for many decades – like everywhere else in the world. Typically, the outcry and demands popping up in the general public, the media, and politics usually recede within some months after high-damage events.

For Europe, the introduction of the Floods Directive (EU 2007) demanded maps for each member country with respect to the flood hazard and risk posed by rivers. Member states have the option to neglect hazard of pluvial floods (caused by limitations of the sewer systems). The directive was an important step towards risk management and risk reduction. Germany made further notable moves forward to improved flood prevention and protection after 2002 and 2013. The 2002 flood initiated a new formulation of prescriptions and restrictions in the Federal Water Act (WHG) that (basically) reads: "Disclosing new settlement areas in designated 100-year flood zones (= typical design flood) is forbidden." This, in principal, welcome specification is however modified – and weakened – by nine exceptions. Only one of these nine points refers to flood damage by stating "Structures have to be designed in a way that no physical damage to them has to be expected when the design flood occurs". The others refer to aspects that are irrelevant for damage reduction, such as health, flood flow, etc. The downside of such a regulation is that there is only little to no leverage by the law to avoid physical losses during events in which the assumptions for the design flood are exceeded. There is hope though that this may be changed: the coalition agreement between the tree parties forming the new German Government (in office since December 2021) includes checking the catalogue of exceptions in the Water Act with the goal to reduce the risks.

One consequence of the 2013 floods was a National Flood Protection Program focusing on the improvement and extension of retention areas to mitigate flood peaks in rivers and on eliminating weak components. The total cost of the more than 100 measures is estimated at almost EUR 5.5 billion (BMUV 2014). The measures, however, are mainly planned along the large rivers.

These actions definitively changed the status of flood prevention in Germany in a positive way. However, they almost exclusively apply to river floods, while protection from local flash floods is hardly accounted for. Several extraordinary events (among others, a 220 mm in 100 min rainfall in the city of Münster, NRW, and destructive flash floods in smaller towns in southern Germany in 2016) raised the awareness for this type of event. Given the characteristics of such local disasters it is mainly the task and responsibility of communities – not that of the federal and state governments – to identify and reduce their own risk. In recent years some communities undertook efforts to better cope with the risk, others did not. The 2021 floods will hopefully contribute to intensify these efforts.

Within the settlements along the rivers the valley floor is stuffed with buildings as the slopes are steep, often geologically unstable, and difficult to build on. Therefore the majority of houses were affected. Traditionally, buildings in Germany are constructed as hybrid structures of masonry and concrete. Structural slabs and basement walls (most of the houses have a basement) are made of cast concrete. The walls above ground are brick-built. Wooden structures are rare, but prefabricated houses have become more common in recent decades. Despite their relatively high potential to resist external forces many houses were destroyed or damaged so severely that they became a total loss. If this was not for the forces of high-speed flow, impact of large debris items or undermining, spilling of oil was often the cause. The majority of houses are heated with fuel oil. Once the oil enters the bricks (burnt adobe or porous concrete) a house becomes uninhabitable. The smell and the unhealthy gas emissions can last for many years. Almost always at least the plastering has to be removed. As a rule of thumb flood water that is contaminated with oil doubles to triples the damage. In at least 13 cases already fully restored houses had to be demolished, because the strong oil smell did not disappear. More such cases are expected.

Contents on flooded floors are normally lost completely after contact with (contaminated) water, mud, feces, and oil. Destroyed furniture and household/office/shop/workshop objects piled up along the rivers as kilometer-long and meter-high heaps – even months after the event. Waste incinerators and dumps were unable to cope with the huge amounts accrued – hundreds of thousands of tons. From the Ahr valley alone some 300,000 tons were transported away, a mass corresponding to the waste amount of 35 years of the whole Ahrweiler district.

5.2 Flood prevention – what needs to be done?

For preventing dramatic losses, it is recommended for residents, enterprises, and communities to reflect sufficiently their individual risk and the potential hazard situation from extreme weather. The first step of risk management and the basis for decisions with regard to future mobile or permanent measures is a sound analysis of the hazard. Permanent structural measures are preferred to mobile solutions because the latter require sufficient lead time for early warning (which is normally not given in the case of a flash flood) and are subject to problems and delays when putting them in place.

Vulnerability of settlements to heavy rainfall can be reduced by enhancing the storage capacity of woodland and agricultural land, restoring flood plains, and by providing extra open, green areas within densely built-up areas. The concept of sponge cities aims definitely in the right direction, although its effectiveness in extreme events may be limited. To raise the risk awareness of the population concepts are needed, ranging from spatial urban planning via early warning systems to evacuation drills and disaster management.

The government cannot provide an overall protection for the individual property, and it cannot fully cover individual private losses. The Federal Water Act states that every individual is responsible for his/her self-protection and self-provision. Flood protection measures to prevent or reduce damage to your home and property is therefore the task of the owner, be it with regard to design aspects of garden and house, or water-proofing of light wells and basement entrances. While it belongs to this responsibility to be informed about protection for themselves and their belongings, the owners must be integrated in the planning processes of communities and authorities early on, kept involved by transparent decision processes, and should be encouraged to realize protection concepts together. Experience shows that the earlier and the more active residents are involved in a protection effort, the better the measures are accepted and applied. Residents can find out from flood hazard maps whether their home (and its neighboring area) may be affected by a river flood or flash flood event and how high the chance is to be hit.

There is a plethora of flyers, newsletters, booklets, and homepages in which authorities, communities, insurers, relief organizations, etc. provide information and recommendations how to protect oneself and one's belongings against flood, windstorm, lightning, landslide, snowstorm, frost, earthquake, etc. To read some of these now and then is advised to get at least a glimpse of proper actions and behavior – and to have an idea where something can be looked up again if necessary.

A quite comprehensive source of information is the handbook of the Federal Office for Civil Protection and Disaster Assistance (BBK) *"The underestimated risks, heavy rain and flash flood*" (BBK 2015). A homeowner in Germany can additionally use "*Flood label"*, a tool that allows assessing the risk situation of a home and provides recommendations to improve it if applicable. Furthermore insurance against flood losses (and other natural perils) is highly recommended for most homeowners and should be taken into consideration. It significantly raises own resilience and may wipe away all concerns about financial consequences after a disaster.

The most effective method to avoid losses is to keep flood-prone areas free from buildings. Unfortunately, the pressure from locals and developers to erect houses, workshops, and plants combined with the communities striving to extend (and raise income by selling land to future owners) is so high that this simple method seldom gets a chance – especially if, at the same time, the legal restrictions are too weak.

5.3 Preparedness and disaster management

Germany is experienced enough to deal well and in a routine way with normal floods, even large ones. But there is a problem with extreme, rare floods. This is partly due to the feeling of having everything under control that is created by managing normal floods well.

There is a distinct difference between local, short-term, high intensity floods caused by convective cloudbursts (pluvial floods, flash floods) and large scale, long-lasting river floods when it comes to the management of a disaster. In the first case local forces are required, which hardly have any time to prepare their emergency activity. This means, these helpers have to have a general, trained and instant capability to react to an event properly and immediately. In contrast to this, a river flood usually allows to prepare for action even though the lead time may only be a day. A picture of the situation can be drawn, possible actions be discussed and a strategy developed.

Often floods are a mixture of both types of event. They start with local flash floods that eventually result in a larger-scale river flood. A third type is a stationary low that not only brings a high rainfall depth but has imbedded cells that can generate intensities comparable to a thunderstorm. The 2021 flood resulted from such an event. It did not only impact one watershed, but hit a number of mid-sized rivers, Ahr, Erft, Rur, Prüm, Kyll, Wupper, each of them with a length in the order of 100 km and catchment sizes between 827 and 2361 km^2.

Since 2004, regular crisis management exercises (LÜKEX) have been conducted every three years, with participation of stakeholders from different departments and sectors. These staff exercises led by the BBK simulate fictive extreme scenarios to prepare for potential catastrophic situations brought up by natural extreme events, technical accidents, terroristic attacks, etc. Existing plans, concepts, and coping capacities are tested and trained in realistic environments. LÜKEX exercises involve crisis management groups of federal and state agencies, operators of critical infrastructure (e.g., power, communication, etc.), and disaster relief organizations.

Besides the professional, well-trained, public actors organized civilian volunteer helpers form the foundation of disaster relief in Germany. They play a decisive role in disaster management, probably more than in any other country. The THW units (Federal Agency for Technical Relief), fire fighters, first aid and relief organizations as well as other federations and consortia with charitable and non-profit goals rely largely on volunteers. Only big cities have professional fire brigades (altogether about 100). In most cases, all members of a fire brigade – from the brigade's chief to the young fireperson – do their job as a volunteer leisure activity, but with the right to be exempted from their job in the case of emergency service. Unfortunately, the German volunteer corps has to fight with lack of new blood in their organizations. Fewer (young) people have decided to devote part of their time to organized relief groups in recent years. One should also not forget that many volunteers involved in relief activities have an own home and an own family that may be affected at the time they are on duty.

When disaster sets a demand, civilian helpers from all over the country would decide to travel to the affected places and offer their help. This enormous willingness to support by helping and donations was experienced right after the flood events in July, too. Every day countless volunteers arrived in the Ahr and Erft valleys to help. This considerably speeded up cleaning efforts.

In this context, organization through social networks has become very helpful and efficient. The problem is that most of these spontaneous volunteers do not come with the basic knowledge about relief work which can only be acquired by training. Such knowledge can contribute to save lives in case of disaster. Civilian self-responsibility is an essential part of strengthening resilience of the society and a strong force in the defense of disasters.

The events of 14 and 15 July and their devastating consequences not only triggered a discussion which preventive measures should be taken by the government to avoid such an extent of losses, but also what the community members can do.

The BBK recommends preparing an emergency plan involving all inhabitants of a house. It helps a lot if all members of a household know prior to an extreme event what she/he has to do, for instance: Who takes care of the young, old, sick persons? Who looks after the pets? Who brings important documents to a safe place? Who shuts off power, gas, heater, etc.? Even more important is to know where certain things are placed or stored: the main power switch, the main gas valve, personal documents, insurance contracts, and not to forget: non-replaceable items such as a family album or inherited items of high personal value.

5.4 Flood insurance

Insurance for flood damage can be bought by homeowners and businesses as an add-on to the regular house insurance that includes cover against fire and storm, and is held by more than 80% of German property owners. Flood insurance is part of a package, together with other elementary perils such as intense rainfall, earthquake, landslide, subsidence, snow pack, avalanche, and volcanic eruption. The German-wide market penetration is about 46%, up from 19% in 2002. This percentage profits from the still 94% penetration in the southwest state (BW); the other 15 states only come up with a 35% average in a range of 23-49% (RLP: 37%, NRW 47%). The reason is that in BW a state-run obligatory insurance scheme was in place until 1994 when it had to be abandoned due to European law (monopoly ban). Major river and flash flood events in 2002, 2005, 2010, 2013, and 2016, together with intense joint marketing campaigns of the insurance sector and most of the federal states, have led to this increase which is still considered too low. Insurance penetration of contents is 28%.

Premiums for flood insurance are based on a rating system named ZÜRS (Zonation system for flood, backup and heavy rain) introduced in 2001. The quality of the system has been improved and extended several times since then, and it is biannually updated to account for changes in the hydrological situation (such as new or raised dikes, changes in flood control works, etc.). Today it consists of four zones: GK4 (Hazard class 4) representing the 10-year flood zone, GK3 the 100-year zone, GK2 the zone that could be affected by an extreme flood (roughly the 200-year flood), and GK1 the remainder, i.e., areas that are unlikely to be affected by a river flood. These zones are computed and defined for all rivers and lakes in Germany with a total length of 55,000 km. 98.5% of all addresses are located in GK1 and GK2 and thus insurable without problem at an affordable price (GK1: 0.02-0.03% of the sum insured). 0.4% is located in GK4 where insurance is very expensive and/or only possible with a high deductible.

Off-plain floods have only been considered by the system since 2019, when an additional rating level for local torrential rain events was presented. The country is subdivided into three heavy-rain classes (SGK) reflecting, 1) locations on a summit or on the upper part of a slope (SGK1, 22% of the area), 2) on middle/lower parts of a slope or on a plain area (SGK2, 66%), and 3) on a valley floor or close to a stream (SGK3, 12%).

After each major flood there has been a discussion about the introduction of an obligatory flood insurance scheme, a solution that is not approved by the Association of German Insurers (GDV). The association proposes a solution that includes flood insurance automatically in future contracts, but with an opt-out clause. This means customers must actively reject to be insured against flood, if they wish so. The GDV demands that this change in insurance policies has to be accompanied by stricter legal restrictions to build in flood-prone areas, codes for flood-resistant construction in certain areas, and climate adaptation measures. In June 2022, the Federal States demanded from the Federal Government to introduce an obligatory insurance for natural hazard, and the Federal Government agreed to examine this possibility.

It is unfair if a government compensates losses to uninsured people using taxpayer's money while the insured get their reimbursement on the basis of contracts for which they paid premiums. Such a policy also undermines damage prevention and loss reduction efforts by the affected. Some German states, e.g., Saxony and Bavaria, have therefore introduced a rule that only those who cannot get a flood insurance cover (e.g., because of their high exposure) may receive compensation by public money. How this rule will be enforced in these states after a future flood is another thing. The political situation at that time (e.g., if an election is ahead) may overrule this well-meant precept.

Losses from automobile insurance constitute often a significant part of the insured losses by floods as partial coverage insurance is widely spread in Germany. Even though most cars suffer a total loss if they are inundated or washed away it is not a good idea trying to save a car that is threatened. A high number of deaths are related to such action and to driving through water during floods. These deaths are definitively avoidable.

The 2021 flood was the highest insured loss ever from a single event in Germany topping the previous record of EUR 4.8 billion in the 2002 Elbe-Danube event. Insurers are expected to pay about EUR 8.5 billion for losses related to "Bernd". Insured property losses for about 213,000 claims amounted to EUR 8.1 billion, motor insurance contributed EUR 350 million (GDV 2022).

6 Reconstruction and future actions

6.1 National reconstruction plan

Only weeks after the flood disaster, the federal and state governments decided to initiate a financial package of up to EUR 30 billion to support the reconstruction of infrastructure in the affected regions and to help the people to re-establish their living conditions. Emergency relief money was provided to private households in the weeks following the flood disaster in the order of EUR 25 million in the Ahrweiler district; for RLP, this help accounted for approximately EUR 33 million. On average, private households received 2,000 euros on-the-spot aid. For additional support, funding from the EU disaster fund was requested.

6.2 Principles and details of recovery and reconstruction

During the reconstruction process some principles have to be followed. Saving human lives has priority, which puts a focus on forecasting, warning, and evacuation. The extent of floods must be mitigated by giving room to the rivers (natural retention areas) and detaining water (dams), wherever possible. Flow obstacles (e.g., narrow bridge openings) must be avoided or removed. Sources of debris in the catchment and along the rivers need to be kept as small as possible. For land-use, structural design, and evacuation planning up-to-date flood maps must be made available, for which historical flood events are considered. RLP has already done this in the second half of 2021, at least in a preliminary version (Fig. 12). At Altenahr gage, for instance, the new 100-year discharge of around 420 m^3/s replaced the previous value of 241 m^3/s.

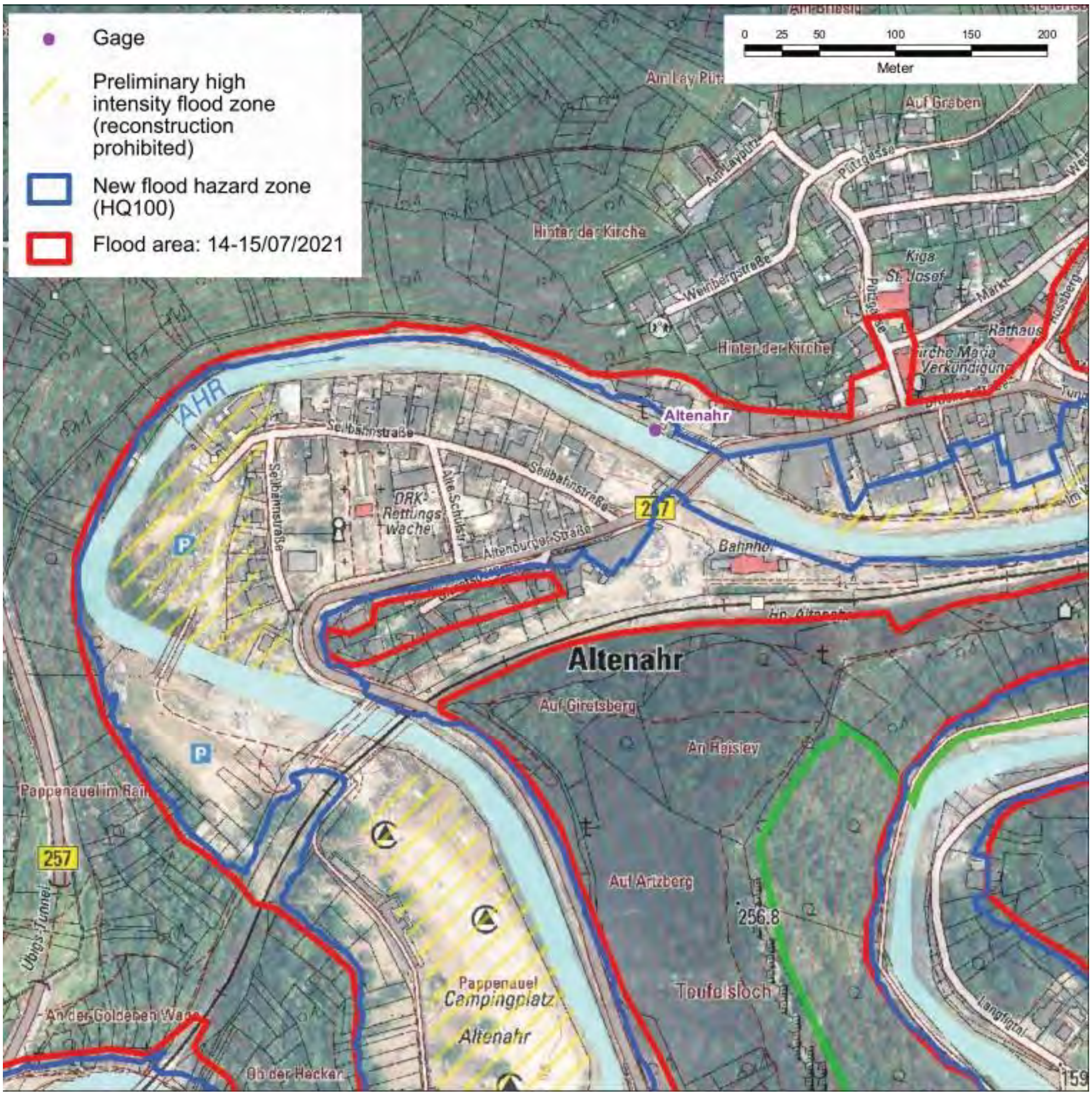

Figure 12: Inundated areas during the July 2021 flood and new – preliminary – 100-year flood area computed after the flood (R. Bell based on SGD Nord 2021)

Reconstruction creates facts. A prime goal in the recovery process is coming up with future high resilience. In building back better, however, a fundamental problem is the conflict between quick recovery and sensible measures. People need homes and traffic facilities as soon as possible, while planning needs time, including sound discussions to integrate the different aspects of a society. Following a decision of the RLP state government, all but 34 houses may be rebuilt at their previous location in the Ahr valley. Time will show how wise this decision is.

The first efforts were to reinstall traffic, power, water and wastewater, gas, and telecommunication systems. These could be fixed within a much shorter time than feared. The supply system for heating gas, in particular, which had been badly affected in Bad Neuenahr could be restored before the winter.

Another high-priority sector was to provide living quarters for those whose homes were lost or uninhabitable. In Sinzig, Bad-Neuenahr-Ahrweiler, and Altenahr, 170 mobile homes (so-called “winter homes”) were set up to allow people who lost their homes to get through the winter. They may stay up to three years in them and pay a very small rental fee. This way, residents can keep their social contacts and connections and are, at the same time, encouraged to stay in the region and do not move away. The mental pressure on people is high anyway, but if, in particular, old, sick, and high-maintenance people have to leave their home environment they receive an additional psychological load. The disaster will most likely have long-term effects for the affected areas. The city of Bad Neuenahr-Ahrweiler originally feared that a third of its 30,000 residents would no longer want to live in the city in the future. That would be a hard loss for this prospering gem in the Ahr valley. According to recent findings, however, this loss will not occur to this extent.

One of the problems after floods is the toxic and unhygienic remains of sludge that cover floors and walls, both in the interior and on the outside. To make houses habitable again, "effective micro-organisms (EM)" are applied. This mixture of various micro-organisms is blended with water and functions like a natural cleaning agent. It is completely biologic and does not contain any chemicals. EM prevents mold, rot, and bad odor.

The immense volume of reconstruction caused a severe shortage of professional construction firms, craft enterprises, qualified skilled workers, and especially construction material. This well-known phenomenon is called "demand surge" and is observed frequently after disasters. Not only prices go up, but unethical and fraudulent offers are made by certain firms. The city of Erftstadt issued a message of caution: "*Be careful when you hand in emergency aid applications. Scammers try to collect personal data.*" In 2021, this post-disaster demand surge coincided with general delays and increasing prices caused by interruptions of supply chains due to the Covid-19 pandemic. The extent, however, to which the pandemic hampered the flood-recovery process needs to be investigated.

Apart from material losses money was also affected directly. The Federal Bank replaced cash of more than EUR 100 million. Bills and coins that were at least 50% preserved were eligible for exchange. Almost EUR 60 million was handed in by private people; the rest went to banks replacing money lost in safes and safe deposit boxes. The drying and counting of the 1.5 million wet, dirty or moldy bills turned out to be a challenge for the Federal Bank. They stuck together, sometimes forming concrete-like chunks, and fell apart during separation. Counting machines could not be used. After treating the bills in laundry driers – with fragrances added against the smell – the counting was done manually. This task was finished by the end of 2021; then the cleaning of 1.2 million coins started.

6.3 Research projects for resilience

The federal government (Ministry of Education and Research) set up several research programs to advise and monitor the reconstruction processes in RLP and NRW with scientific expertise.

KAHR stands for Climate adaptation, Flood and Resilience. The program is endowed with EUR 5.2 million in the period 2021-2024. Its aim is to provide newest scientific findings about climate adaptation and disaster management to the stakeholders during reconstruction, aiming at a sustainable and climate-resilient construction status. 13 partners from various disciplines are involved in advising stakeholders at different scales (communal, regional, statewide, national). Proposed prevention measures will be assessed and tailored to the respective local needs. The concepts developed for flood and extreme rainfall will go beyond defining flood zones. Spatial planning and precautionary measures at the property level will be strengthened, and capacities for coping with future – possibly stronger – events will be optimized by cooperation of the water resources management, disaster management, and regional planning sectors.

Another interdisciplinary project, HoWas2021, deals with "Governance and communication during the crisis of the July 2021 flood", and is funded with EUR 1.5 million for 18 months. Five universities and a number of federal, state, and private stakeholders look into improving forecast procedures and warnings, the communication during a crisis, and disaster management when dealing with extreme weather situations. Via expert interviews, meta-analyses, and selected case studies in the flood affected regions the different phases of responding to the disaster are analyzed, particularly focusing on civil protection organizations and long-term reconstruction.

In addition to the physical reconstruction process one must not forget the mental recovery process of the people. Hundreds if not thousands of people probably have developed a posttraumatic stress disorder (PTSD) when they saw their belongings and thus their "life" sinking into water. PTSD can occur even weeks and months after the underlying event. Experience shows that about 30% of survivors of natural disasters suffer from this disorder. Symptoms are: flashbacks (i.e., the disturbing scenes re-enter people's minds), increased suicidal tendency, anxiety disorder, depression, somatization disorder (i.e., inexplicable pain without physical cause), and panic attacks. It is necessary to provide psychological assistance to these people. To meet these demands, a trauma counseling center was established in the Ahr valley in December 2021.

7 Conclusions

7.1 Factors responsible for the disaster

The following factors were crucial for the July 2021 floods in Germany:

1. Extreme precipitation with regard to both total amount and intensity, related to a quasi-stationary weather pattern in Europe;
2. Low retention potential in the catchments due to antecedent wet conditions and topographical characteristics;
3. Very swift runoff on surfaces, short concentration times, and torrential flow in the watercourses due to steep slopes in the affected regions;
4. Fast rising water levels and quickly increasing flow velocities, sometimes locally enhanced by clogging of bridges and other flow obstacles;
5. Water flowing several meters high through low-lying areas even distant from the river after overtopping the banks, thus creating high risk to people and high destructive power to buildings and other structures;
6. Damage to structures (e.g., buildings, bridges) by impact of large objects such as logs, vehicles, and other floating debris;
7. Erosion of river channels, scouring, undermining of structures, and sediment deposits (debris, mud);
8. Problems and delays in early warning procedures and evacuation;
9. Hazard maps that did not reflect the actual situation adequately;
10. The surprise effect combined with the disbelief of people and (of some) disaster managers that this kind of event was actually coming up.

Flood disaster management can only be successful if all components of risk – hazard, exposure, vulnerability – are reduced effectively. The improvement of early warning systems and the education of the civil society require precise knowledge about the risks in the area concerned based on reliable hazard and risk maps, with a particular focus on critical infrastructure.

It was obvious that the danger posed by the flood in July 2021 was underestimated. Warning level 4 was issued by the DWD in due time, but the urgency of this information got partly lost on the way to stakeholders and individuals. Deaths on flooded streets and in inundated houses show that warnings did not reach people in time or were not specific enough so that they could act adequately. However, individual misbehavior was certainly also a factor in many cases.

Evacuation is usually based on hazard and risk maps that show potentially flooded areas. These maps must be up-to-date and consider possible alterations due to climate change. They should reflect historical floods and their inundation areas. Missing references to former events (anchor examples) exacerbate the assessment of measures and their enforcement. Furthermore, areas that will be flooded if dikes and other protection structures fail must be indicated as well as the time when a flood wave is likely to arrive from the catchment (concentration time) and flow velocities in given areas. Inaccurate maps may cause wrong decisions. A short time span from rainfall to flooding of buildings and flows with a high destruction potential requires extremely fast decision making.

The knowledge and risk perception of institutions and population are crucial for how fast and comprehensive emergency measures are undertaken. The understanding of warning levels and risk maps in the population is less pronounced for flash floods than for river floods as polls showed in Germany. Only those who react in a proper way can reduce consequences for health and objects. Innovative technical warning devices and methods must be complemented by educational and communicational measures.

Impact-based warnings or even more specific predictions of impact have a great potential to improve the reaction in a crisis. They may identify buildings and infrastructure components which are presumably flooded. Existing flood forecast models must be extended by model components that assess the inundated areas and potential consequences (danger zones, potential damage).

These conclusions result in lessons to be translated in the three following sectors:

7.2 Structural prevention and flood risk management

Extreme flash floods cannot be avoided, but flood-proof and flood-resistant buildings together with permanent structural protection measures can reduce damage. The design of new bridges must take into account the large amounts of sediment, debris, and floating matter carried by flood waters, and result in larger openings. If possible, a construction style that shows resilience during extreme events should be chosen. This means, the bridge should not only withstand the physical loads during the flood, but the water should be able to flow past the structure without significant backup and erosion of the banks even if its opening is clogged. To ensure that, drive-up ramps should be designed to be overflown without being eroded. Eventually the bridge must be usable immediately after the flood waters have receded, preferably with no or little damage.

Operational flood protection and flood management must foresee possible extreme scenarios even if they do not appear likely. The technical possibilities to deploy and prepare communication must be checked with all potential stakeholders and actors during a crisis. The BBK demands more involvement and cooperation of the agency with the crises management groups of the federal states. For better coordination a competence center for civil protection should be established, involving BBK, the 16 federal states, relief organizations, and rescue teams. There must be standards such as consistent maps and terminology used by all actors involved, authorities, water resources agencies, disaster relief units, and citizens. Exercises should be established. It is more than a buzzword to demand: "Practice – practice – practice!".

7.3 Early warning and behavior

Elementary and timely information and preparation for the case of emergency is vital. The high number of deaths led to the conclusion that many residents were not adequately informed about the threats they had to expect in their homes, how to prepare, and how to (re)act during the event. The pure meteorological statement must be translated into a concrete danger (potential consequences) and accompanied with specific instructions what to do. Only then communities and residents can understand it and put it into action.

An efficient early warning system is one of the most important components of disaster prevention. Such a system must be robust and have redundancies, including staff and media that do not require the power network. Its structure should be adapted to regional demand so that it may be applied to a small catchment. This needs to take into account local contexts and potential impacts.

The recipients (population and disaster management actors) have to be educated, informed, and trained with regard to risk knowledge. This can be done via schools, TV spots on warning, hazard maps, leaflets, and short courses on adequate behavior. Risk knowledge involves to have emergency plans and, for individuals, a notion how to behave adequately. Tools and devices for flood defense should be at hand. Insurance cover is highly recommended.

7.4 Spatial planning

Flood-aware spatial planning keeps flood paths activated during extreme discharges free of houses and other structures such as roads, railroad tracks, drive-up ramps to bridges, and plantings. To avoid damage one should refrain from developing and building in flood-prone areas. With regard to reconstruction this may mean: replace the demand "Build Back Better" by "Build Back Elsewhere" wherever achievable. Identification of places where water may gather or accumulate (depressions) and its preferential paths during heavy rainfall helps to prevent losses. Flow paths to convey the water without severe consequences should be provided.

Official databases of event and loss data are missing. So far, private companies (e.g., reinsurers) and non-governmental institutions (e.g., university institutes) have provided the service of collecting these data, but this way is not complete, reliable, and sustainable. A company may decide overnight to resign from a service – and nobody can prevent it. At a university, its functioning may depend on a single person and end when that person leaves or funds are cut. Data collection, processing, and provision must therefore be done as a public, guaranteed task. Apart from their meaning for accounting, these data are a valuable basis for disclosing development areas and disaster statistics.

Germany's legal restrictions are too weak when it comes to erecting a building in a high-hazard zone. In Switzerland, for instance, project planning forbids building in a "red zone" without exception. Sponge cities with less sealed areas, more parks, and green roofs can store water, thus not only reducing the urban runoff but, at the same time, improving the urban climate with their influence on humidity, air quality and temperature.

Future focus in a comprehensive flood risk management and disaster reduction must be done as a common, joint task involving regional and urban planning, traffic planning, meteorology, hydrology, hydraulic engineering, social sciences, communication, administration, and disaster relief organizations to name a few. Scientific knowledge and new findings must be conveyed in a way that everybody can understand them. Decision makers and people must be convinced to trust in and rely on scientific expertise. Planners and decision makers, for their part, must reach more people with their recommendations. Knowledge is present, but often experts do not succeed in getting it to the political and societal space, i.e., the people.

The flood disaster of July 2021 has revealed that not only research on extreme weather has to be conducted but early warning, preparedness and precautionary measures need improvement. Additionally, there must be political guidelines dealing with heavy rain and flash flood in particular. For this purpose, measures are required that differ from those applicable to river floods.

References

BBK (2015): Die unterschätzten Risiken Starkregen und Sturzfluten (*The underestimated risks of heavy rain and flash floods*).
https://www.flussgebiete.nrw.de/system/files/atoms/files/bbk_starkregen.pdf (in German)

BBK (2022): Das Modulare Warnsystem (MoWaS) (*The modular warning system MoWaS*)
https://www.bbk.bund.de/DE/Warnung-Vorsorge/Warnung-in-Deutschland/Warnmittel/MoWaS/mowas_node.html (in German)

BMUV (2014): NHWSP – Liste prioritärer Maßnahmen zur Verbesserung des präventiven Hochwasserschutzes (*List of priority measures for the improvement of preventive flood protection*)
https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Binnengewaesser/hochwasserschutzprogramm_massnahmen_bf.pdf (in German)

DKKV (2022): Opfer- und Schadensdaten der Flut 2021 in Rheinland-Pfalz (*Figures of victims and losses of the 2021 flood in Rhineland-Palatinate*); German Committee for Disaster Reduction, Bonn
https://www.dkkv.org/fileadmin/user_upload/Anfrage_Opfer-_und_Schadensdaten_der_Flut_2021.pdf (in German)

DWD (2021): Hydro-klimatologische Einordnung der Stark- und Dauerniederschläge in Teilen Deutschlands im Zusammenhang mit dem Tiefdruckgebiet „Bernd" vom 12. bis 19. Juli 2021 (*Hydro-climatic classification of heavy and continuous rainfall in parts of Germany in the context of low "Bernd" from 12 to 19 July 2021*).
https://www.dwd.de/DE/leistungen/besondereereignisse/niederschlag/20210721_bericht_starkniederschlaege_tief_bernd.html (in German)

DWD (2022): Wetter und Klima – Warnkriterien (*Weather and Climate – Warning criteria*); German Weather Service
https://www.dwd.de/DE/wetter/warnungen_aktuell/kriterien/warnkriterien.html (in German)

EU (2007): Directive 2007/60/EC on the assessment and management of flood risks, European Commission. https://ec.europa.eu/environment/water/flood_risk/

Fraunhofer (2022): Fraunhofer FOKUS | WE CONNECT EVERYTHING. https://www.fokus.fraunhofer.de/en

GDV (2021): Naturgefahrenreport 2021 (*Natural Hazards Report 2021*). Association of German Insurers, 64 pp. https://www.gdv.de/resource/blob/71294/ebaad3ff1563be2b92e0dd0ce4c0751c/download-naturgefahren-report-data.pdf (in German)

GDV (2022): Ein Jahr nach der schadenreichsten Naturkatastrophe in Deutschland: Versicherer ziehen Bilanz zur Schadenregulierung (*One year after the natural disaster in Germany with the highest losses: Insurers draw a balance of claims settlement*), Association of German Insurers, Media information on July 6, 2022 https://www.gdv.de/de/medien/aktuell/ein-jahr-nach-der-schadenreichsten-naturkatastrophe-in-deutschland-versicherer-ziehen-bilanz-zur-schadenregulierung-85458 (in German)

Hoffmann, P., Lehmann, J., Fallah, B. et al. (2021) Atmosphere similarity patterns in boreal summer show an increase of persistent weather conditions connected to hydro-climatic risks. *Sci Rep* **11,** 22893 (2021). https://doi.org/10.1038/s41598-021-01808-z

IPCC (2021): Climate Change 2021: The Physical Science Basis. AR6 Climate Change 2021: The Physical Science Basis — IPCC. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Kirschstein, G. (2022): Die Katastrophe war um 17.17 Uhr sichtbar (*The disaster was visible at 5:17 pm*), Rheinzeitung 2022/2/31 (in German)

Kreienkamp et al. (2021): Rapid attribution of heavy rainfall events leading to the severe flooding in Western Europe during July 2021. https://www.worldweatherattribution.org/heavy-rainfall-which-led-to-severe-flooding-in-western-europe-made-more-likely-by-climate-change/

Kron, W., Eichner, J. & Kundzewicz, Z.W. (2019): Reduction of flood risk in Europe – Reflections from a reinsurance perspective. Journal of Hydrology 576, 197–209. https://doi.org/10.1016/j.jhydrol.2019.06.050

Munich Re (2022): Hurricanes, cold waves, tornadoes: Weather disasters in USA dominate natural disaster losses in 2021, Munich Re. https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2022/natural-disaster-losses-2021.html

Roggenkamp, T. & Herget, J. (2014): Reconstructing peak discharges of historic floods of the River Ahr, Germany. Erdkunde Vol. 68, No. 1, 49-59

RTBF (2021): Inondations de juillet 2021: 71,746 dossiers d'indemnisation introduits auprès des assureurs (*71,746*

loss claims filed according to insurers). Radio Télévision Belge Francophone
https://www.rtbf.be/article/inondations-de-juillet-2021-71746-dossiers-dindemnisation-introduits-aupres-des-assureurs-10868318 (in French)

SGD Nord (2021): Struktur– und Genehmigungsdirektion Nord, Überschwemmungsbiet der Ahr, Übersichts- und Detailkarten (*Flood area of the Ahr, Overview and detail maps*), Sep. 2021.
https://sgdnord.rlp.de/fileadmin/sgdnord/Wasser/UESG/Ahr/Arbeitskarten/Ueberschwemmungsgebiet_Ahr-Arbeitskarten_Zukunftskonferenz.pdf (in German)

Thieken, A., Mohor, G., Kreibich, H. & Müller, M. (2022): Compound flood events: different pathways, different impacts and different coping options. NHESS 22, 165-185.
https://doi.org/10.5194/nhess-22-165-2022.

3. Overview of Major Water-Related Disaster in Japan in 2021 and progress on the new policy, "River Basin Disaster Resilience and Sustainability by all"

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1.1 Overview of the Water-related disaster and risk reduction policy in Japan

Water-related disasters hit Japan every year. Disasters struck Izu-Oshima island in 2013, Hiroshima city in 2014, the Kanto-Tohoku region in 2015, the Hokkaido-Tohoku region in 2016, Northern Kyushu region in 2017, a widespread area in Western Japan in 2018, Northern Kyushu region and a widespread area in Eastern Japan in 2019 and Kumamoto Prefecture in Kyusyu region in 2020.

Heavy disasters are annual events in Japan, therefore the central and local governments are most often in a cycle of preparedness, disaster, response, and recovery. In the cycle, Japanese society has been urging policy-makers and infrastructure managers to reduce disaster risks and damages and to prevent disasters from events of similar scales in the future. Post-disaster work is preparation in view of the next one. This is the basic concept of "Build Back Better". However, disasters vary in magnitude and frequency, and people living in disaster-prone areas have to face unprecedented events.

This chapter describes the overview of the flood disaster by torrential rain in 2020, and the policy-making process by MLIT based on the changes in the climate and social environment.

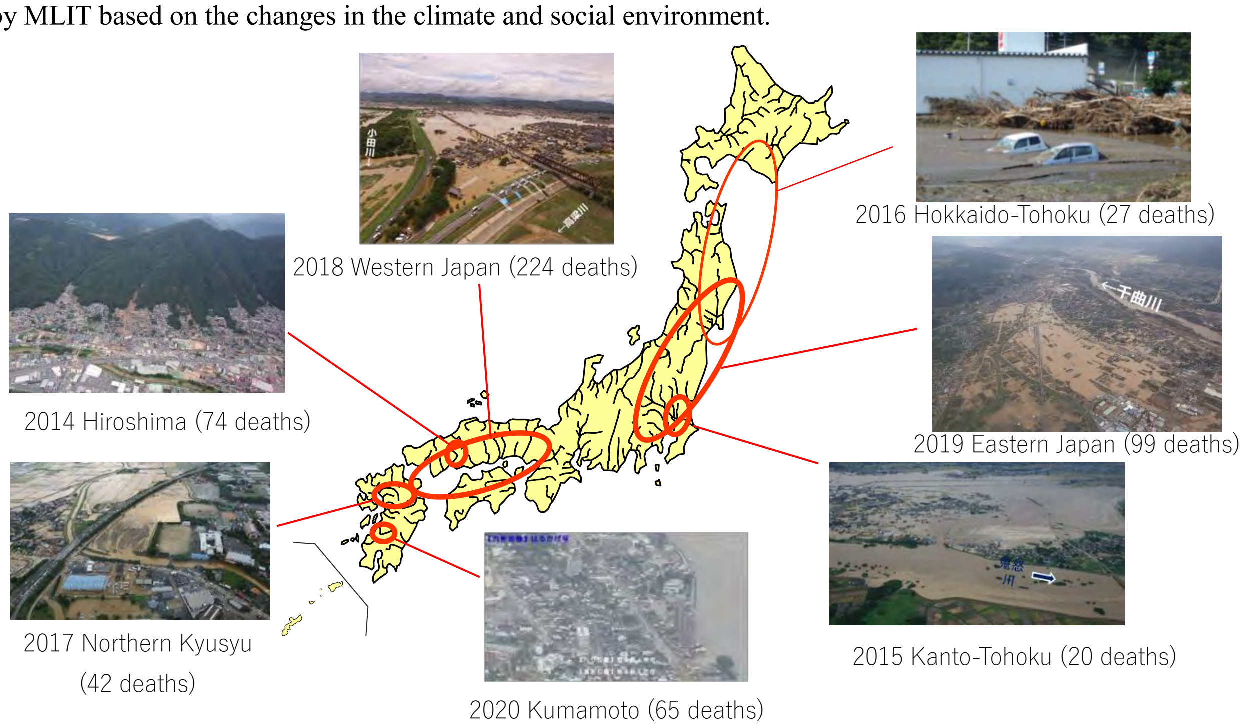

Fig. 1 Successive water-related disasters hitting Japan

1.2 Overview of Heavy Rain Events in 2021

1.2.1 Overview of the Heavy Rain Events in July 2021 (as of 4 November 2021)

From early to mid-July, the rainy season front stalled near Japan, resulting in heavy rainfall in many areas. From July 1 to 3, heavy rainfall occurred mainly in the Tokai region and the southern part of the Kanto region, with several points in Shizuoka Prefecture recording the highest 72-hour rainfall in recorded history. From July 9 to 10, the total amount of rainfall exceeded 500 mm, mainly in Kagoshima Prefecture.

Damage due to flooding and erosion was confirmed in 56 rivers of 26 water systems with 979 inundated houses, while inundation was observed in 64 rivers in 30 river systems. 273 sediment-related disasters were confirmed with 26 casualties, 1 missing, and 127 damaged houses.

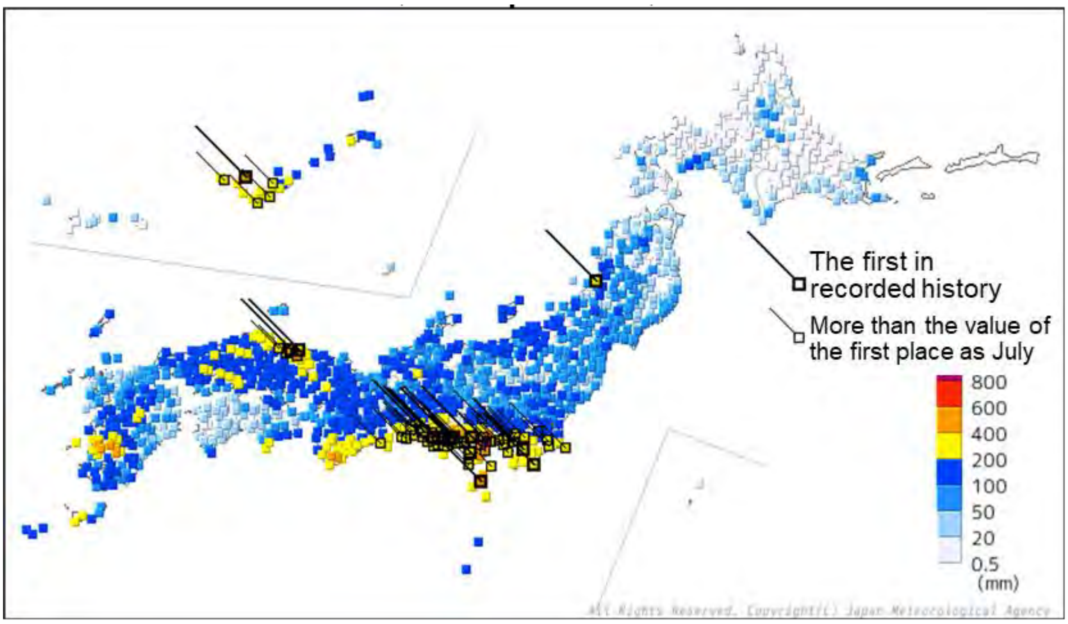

Fig. 2 Maximum 72-hour rainfall for the period (Period: June 30, 2021 - July 12, 2021)

Damage caused by Mudslides
(Atami City, Shizuoka Pref.)

Slope collapse at Zushi Interchange
(Zushi City, Kanagawa Pref.)

Overflow and Inflow
(Rokkakugawa River)

Takata, Nishi-ku, Hiroshima City,
Hiroshima Pref.

Fig. 3 Examples of Damages by Heavy Rain Events in July 2021

1.3.2 Overview of the Heavy Rain Events in August 2021 (as of 16 November 2021)

From August 11 to 19, the activity of a stagnant front near Japan increased, with linear precipitation zones occurring in the northern Kyushu region on August 12 and in the Chugoku region on August 13.

Especially in the northern part of Kyushu, fierce and very heavy rains due to linear precipitation belts continued to fall, and the city of Ureshino in Saga Pref. experienced record-breaking heavy rains, including the highest 24-hour rainfall in recorded history.

Damage due to flooding and erosion was confirmed in 67 rivers of 26 river systems, with 894 inundated houses, while inundation was observed in 89 rivers in 29 river systems. 413 sediment-related disasters were confirmed with 9 casualties and 90 damaged houses.

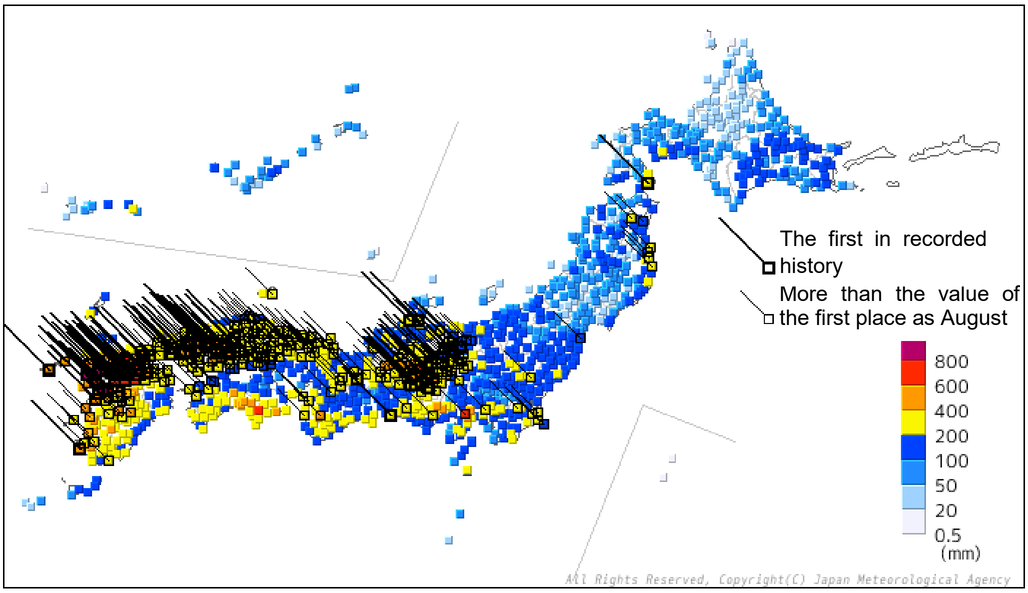

Fig. 4 Maximum 72-hour rainfall for the period (Period: August 11 - 26, 2021)

Overflow
(Gounogawa River)

Levee Broken
(Tajihigawa River)

Overflow and Inflow
(Rokkakugawa River)

Takata, Nishi-ku, Hiroshima City,
Hiroshima Pref.

Fig. 5 Examples of Damages by Heavy Rain Events in August 2021

1.4 Progress on the new policy, "River Basin Disaster Resilience and Sustainability by all"

1.4.1 Background

The Panel on Infrastructure development issued a report on water-related disaster risk reduction (DRR) considering climate change in July 2020. The report has recognized the enormous damages by recent water-related disasters, advanced reconstructive actions based on the former “water-related DRR conscious society”, and advocated the water-related DRR with the concept of the “River Basin Disaster Resilience and Sustainability by All”, which calls for all stakeholders to consider DRR as natural, mainstream DRR, and take collaborative actions in each river basin including watershed and flood plain area.

MLIT has been developing and implementing DRR measures based on the report to achieve a resilient and sustainable society against water-related disasters under the impact of climate change. The following paragraphs overview the new policy and progress on implementing the policy in 2021.

1.4.2 Climate change impact on precipitation in Japan.

The future forecast by climate change assumed the intense rain in short duration, more frequent and intensified rainfall, more total rainfall, the rise of the average sea level, more sea-level deviation from normal. There is fear of the occurrence of severe and frequent water-related disasters and another mega-disaster combined landslide, flood, storm surge, and inundation.

The records of precipitation show the increase of frequency is about 1.4 times for hourly precipitation above 50mm, and about 1.7 times for hourly precipitation above 80mm, compared with about 30 years before

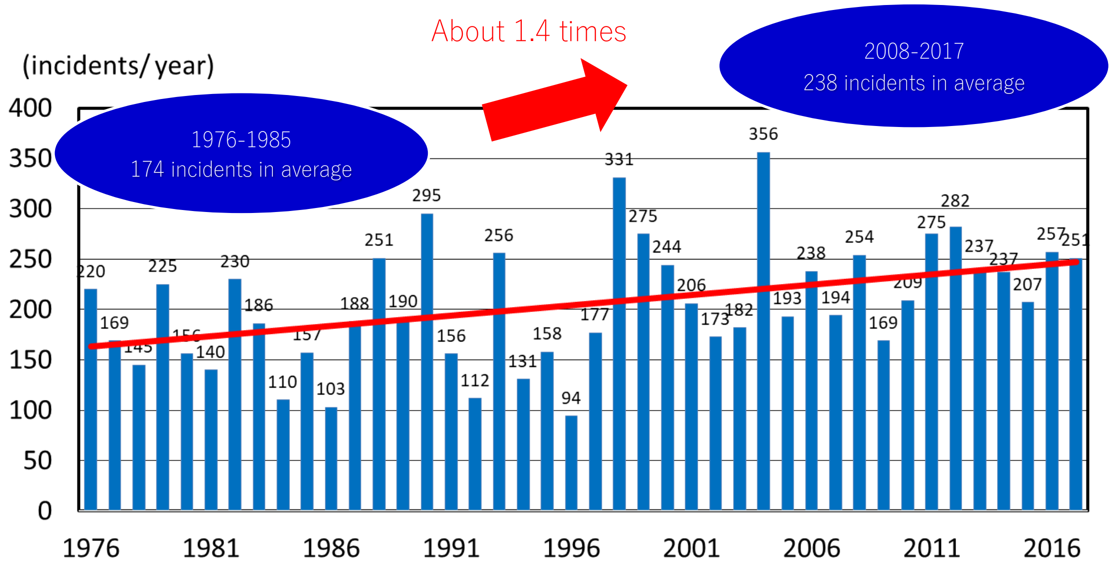

Fig. 6 The trend of the frequency of rainfall (50mm / hr or more) in the last 30 years in Japan

MLIT established the Expert Group meeting for flood control plan under climate change to estimate the rainfall increase in the future, which provides the assumed information on facility design based on the flood control plan. It is estimated that about 1.3 times increase in the target rainfall, about 1.4 times increase in the flood flow, and about 4 times the average frequency of flood, for flood control plan in the major rivers from the end of the 20th century to the 21st century in the case of 4-degree rise of world average temperature compare to before the Industrial Revolution. Even in the case of 2-degree rise (target scenario for the Paris Agreement), the result estimated about 1.1 times increase in the target rainfall, about 1.2 times increase in the flood flow, and about 2 times in the average frequency of flood, for flood control plan in the major rivers from the end of 20th century to 2040 in the major rivers.

<The expected changes in the precipitation by region>

Region	2℃ increase	4℃ increase	
			short time
Northern and Southern Hokkaido	1.15	1.4	1.5
Northwest Kyushu	1.1	1.4	1.5
Others including Okinawa	1.1	1.2	1.3

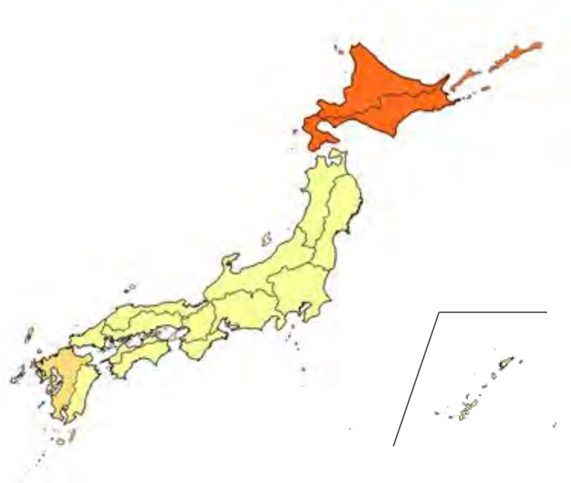

Fig. 7 The expected change in precipitation by temperature increase

1.4.3 Overview of the new policy, River Basin Disaster Resilience, and Sustainability by All

MLIT is promoting the following measures to implement the new flood management policy, River Basin Disaster Resilience and Sustainability by All:

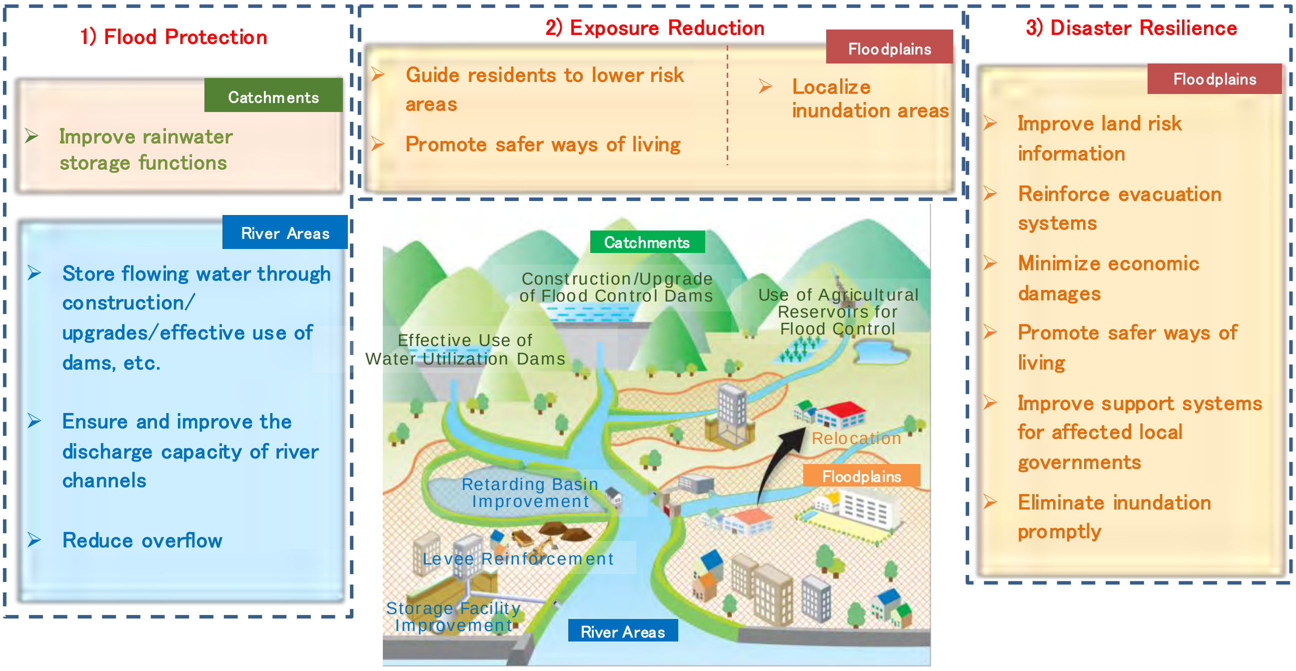

Fig. 8 Image of the new policy, "River Basin Disaster Resilience and Sustainability by all"

1) Flood Protection - Enhancement of flood prevention measures

It is necessary to enhance and effectively combine flood prevention measures such as storing rainwater and running water, increasing the discharge capacity of rivers, and controlling flooding water for improving safety against water-related disasters in the whole basin.

It is first necessary to further accelerate ongoing structural measures such as embankment improvement, channel dredge, dam and retarding basin construction by river administrators, and the improvement of rainwater line and underground storage by sewage administrators.

It is important to ask for cooperation from the stakeholders who have not been consulted previously. The platform where such stakeholders can cooperate for the basin management should be set and flood prevention measures such as the implementation of preliminary discharge by water users' dams, installation of rainwater storage/penetration facilities around urbanized/populated areas by local governments or private sectors, and conservation of forests and agriculture lands to maintain water-holding and retarding function, considering the characteristics of the river basin. Further, the technological research and development about embankment reinforcement should be advanced for "persevering embankment" difficult to burst even if flooding occurs. This can reduce the flood amount during flooding, at higher risks in particular.

2) Exposure Reduction - Measures to reduce a damaged target

The flood prevention measures are primarily taken to reduce water-related disaster risks, but it is also desirable to take the measure for damage minimization as well in case that flood may occur. Specifically, following measures are effective for reducing flood damages: regulation for land use and way of living in water-related high-risk areas, leading resident and urban function to the lower risk areas, limiting the flooded area, the augmentation in land for housing in an area with flooding risk, and the device of building structure.

Land use and the building structure have been regulated by designating the high-risk area as a hazard area, but these were performed with river works. There is still new development even in the area with high water-related hazard risk, and flood damage occurs there. Therefore, it is important to collaborate with urban planning sectors, connecting water-related disaster risk reduction with "compact plus network", lead to the low-risk zones and give devices of how to live. For local revitalization, the community should take the leading measures for urban planning resilient to water-related disasters according to each characteristic.

It is necessary that all kinds' information about water-related hazard risk is being estimated appropriately and is being reflected in actual measures. Risk information about water-related disasters has been published mainly for smooth evacuation by residents to protect their lives, but these should be improved for urban planning. Water-related hazard risk evaluation should apply to the risk reduction around a whole basin

3) Disaster Resilience

The damage to people's live and social economic assets should be minimized even when floods and sediment disasters become inevitable. Public sectors should provide the information on water-related hazard risks appropriately. It is important that every stakeholder in the basin have information and attitude on water-related disasters, prepare beforehand, and take appropriate actions during the disasters.

Various measures for more effective evacuation have been taken place, such as designating flood forecast and flood alert rivers for flood suffered rivers, preparation of flood hazard area maps, flow observation, and providing information to the resident.

Besides, the flood fighting act was amended to oblige facility managers to prepare a flood prevention plan and to conduct evacuation drill for underground facilities with high flood risk, and to prepare a plan to secure evacuation for welfare facilities for people who need special assistance. The national and local governments have been cooperating to support the facility managers to implement the obligations.

The evacuation drill and disaster risk reduction education have been implemented all over the country for awareness raising and effective evacuation. "My timeline" has been developed as an individual action plan for emergency situations.

The 2019 Typhoon Hagibis shows the damage to people's lives in the water-related risk information blank areas as well as in the estimated flood inundation areas because of escape delay. Evacuation system should be further improved by reinforcing existing activities.

National support including TEC-FORCE has worked for assistance to affected areas as measures of early response and recovery. Such support mechanism by national government should be reinforced and strengthened by the cooperation among all stakeholders in a whole river basin.

1.4.4 Major Progress in 2021 – Amendment of Related Laws and Acts to Promote the new Policy

The "Law to partially revise the Act on Countermeasures against Inundation of Rivers in Specified Cities" was enacted in the Diet in April 2021 and promulgated in May 2021, in order to Strengthening flood control plans and systems and enhance the effectiveness of basin management.

This law amendment is an integrated revision of nine laws, including the River Law, Sewerage Law, Flood Control Law, City Planning Law, Urban Green Space Law, and Building Standards Law, in addition to the Specified City River Inundation Damage Countermeasures Law.

Specifically, a legal framework was established to enhance the effectiveness of "basin hydraulic control" for the following four items.

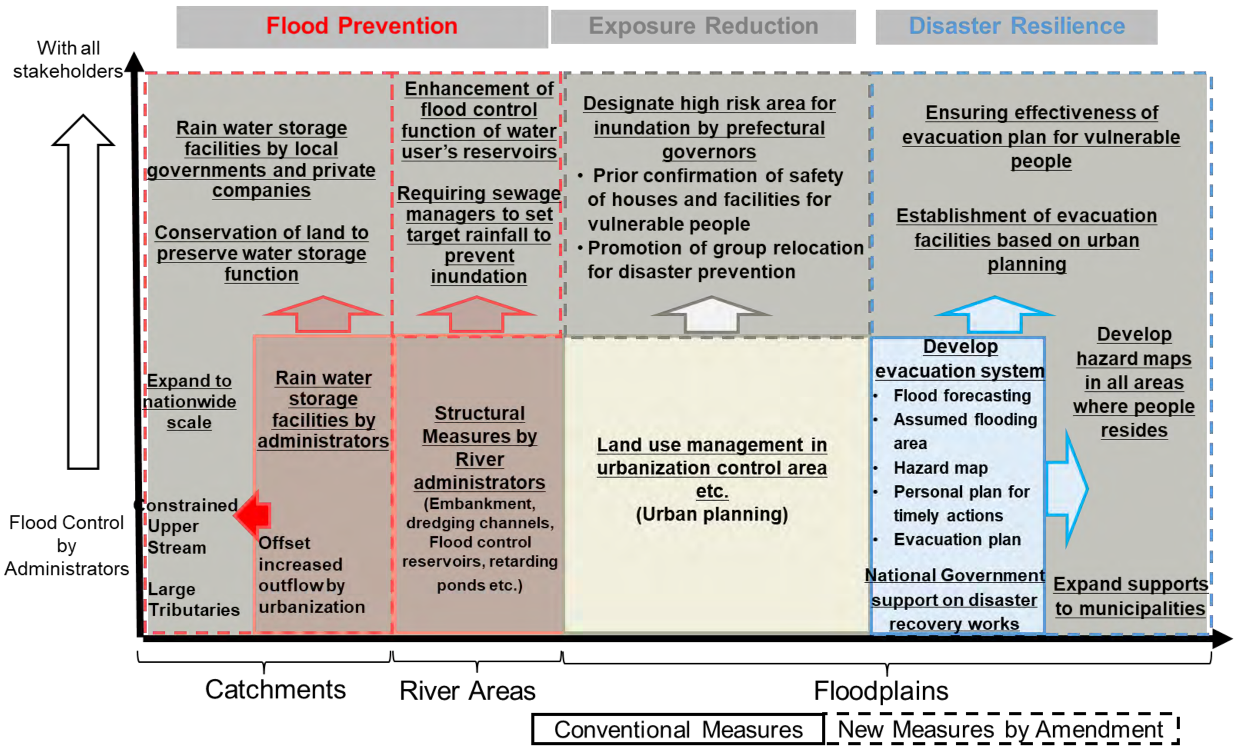

Fig. 9 Image of the amendment of the laws and the acts to promote the new policy

The Amendment was comprised of four pillars as follows.

(1) Strengthening flood control plans and systems

・Expansion of rivers utilizing basin flood control plans

: Expand target rivers from Rivers with increased flood risk due to urbanization to all major rivers in Japan

・Establishment of Basin Flood Control Councils and enhancement of plans

: Relevant parties from the national, prefectural, and municipal governments gather together to discuss land use in inundation areas to strengthen public and private measures of rainwater storage and infiltration.

: Discussion results will be incorporated in the flood control plans.

(Example of enhancement of flood control plans)

・Promote rainwater harvesting and infiltration measures in river basins, in addition to the river improvement works river administrators

Before	○ **Focus on** rainwater harvesting and infiltration **measures by river and sewerage administrators**
Added	○ **Clarification of the amount of storage shared by local government facilities and certified private facilities**
	○ **Land use policy (conservation of land with water retention functions, ensuring safety of housing and other facilities in areas of extreme danger)**

(2) Measures to mitigate inundation

(Strengthening measures for rivers and sewers)

・Establishment of a council (with river managers and water users such as electric power companies etc.) to plan preliminary discharge before flooding for water utilization dams

・Set target rainfall to prevent flood damage in the sewerage plan and accelerate flood control measures in the sewerage system.

・Mandatory formulation of operating rules for sewer drainage gutters

（Strengthening measures for rainwater storage in basins）

・Establishment of a system to secure land with water retention and retarding basins along the river

・Conservation of urban green spaces with rainwater storage and infiltration functions

・Support for the development of local and private rainwater storage and infiltration facilities through certification systems and subsidies, etc.

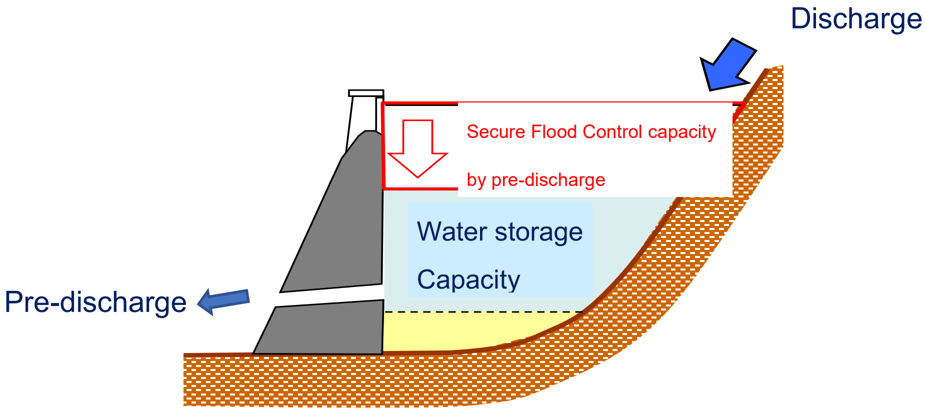

Fig. 10 Image of pre-discharge of dam to secure flood control capacity

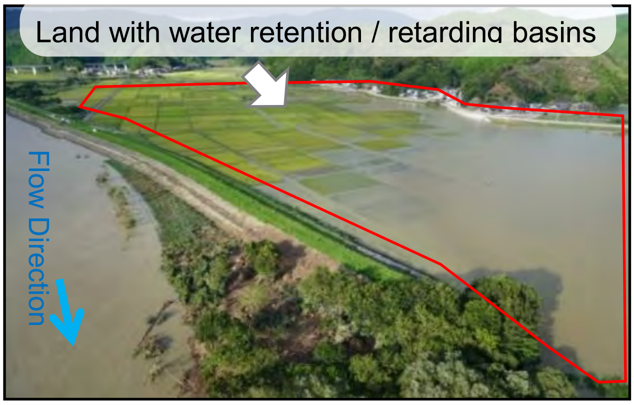

Fig. 11 Image of secure land with water retention and retarding basins along the river

(3) Measures to reduce the damage target

・Establishment of a system to confirm the safety of flood damage in advance, such as housing and facilities for people requiring special consideration

・Expansion of area requirements for disaster prevention group relocation promotion projects

・Promotion of development of evacuation bases in the event of a disaster

・Promotion of flood control measures for each district

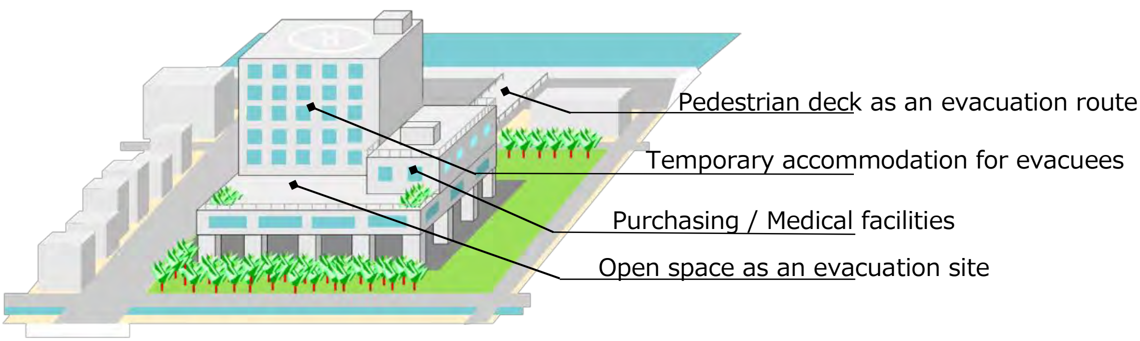

Fig. 12 Image of development of evacuation base

(4) Measures for damage reduction, early recovery, and reconstruction

・Expand the target rivers for creating flood hazard maps to small and medium-sized rivers

: Number of target rivers to develop hazard map and designate provable inundation area will be expanded from current about 2,000 to about 17,000 by fiscal year 2025

・Establishment of a municipal advice / recommendation system for evacuation plans for facilities for people requiring special attention

・Expand MLIT's direct support for early recovery to rivers managed by municipalities with additional target projects such as removal of trees, earth and sand accumulated from disasters.

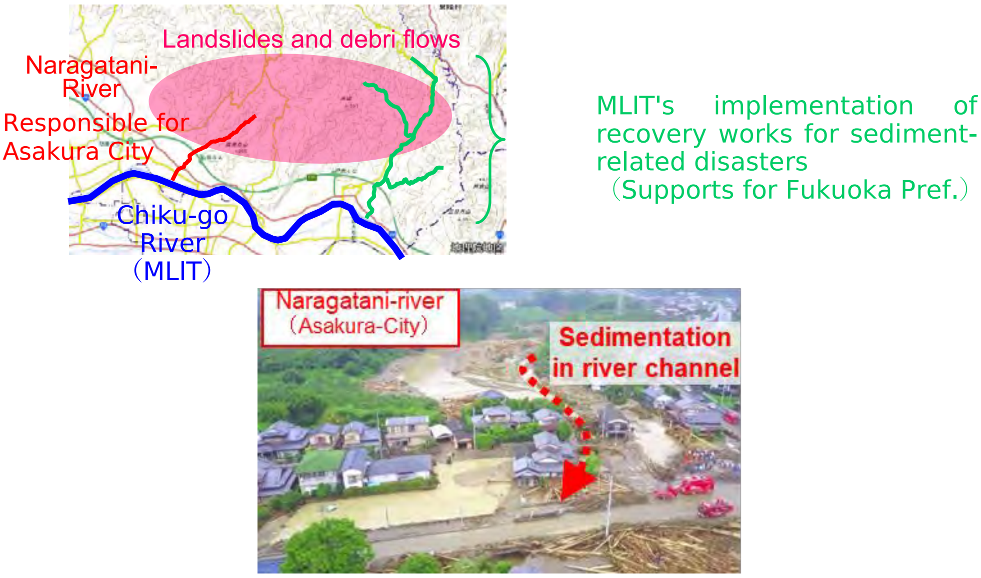

Fig. 13 Example of expected MLIT's supports for disaster recovery

2017 Heavy rain in Northern Kyu-syu (Chikugo-river)

1.4.5 The Way forward

MLIT commenced to review flood control plans of main rivers by reflecting the estimation of increases in heavy rain by 2100 based on the latest scientific knowledge. The National Diet approved the amendment of related laws in April 2021 to take all possible actions throughout river basins towards water-related disaster risk reduction, by utilizing existing storage facilities and strengthening the functions of forests and agricultural lands to suppress outflow.

A basin can be a family. It is desirable that all stakeholders in the basin can cooperate than before, and think what they can do for the total damage reduction, under the recognition of each resident membership.

MLIT will strengthen its efforts to implement the new policy and accelerate structural and non-structural measures with close cooperation with all stakeholders in a basin.

4. Hurricane Ida and beyond: U.S. Army Corps of Engineers' disaster preparation, response and strategy

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Hurricane Ida

Hurricane Ida was the second-most intense hurricane to strike the state of Louisiana on record, behind only Hurricane Katrina.[1] It tied for the strongest landfall by maximum winds in the state with Hurricane Laura in 2020 and the Last Island hurricane in 1856.[2] The storm originated from a tropical wave first monitored by the National Hurricane Center (NHC) on Aug. 23, 2021, as it moved into the Caribbean Sea. The storm rapidly intensified starting Aug. 28 as it moved into the Gulf of Mexico, which was experiencing very warm sea-surface temperatures and light wind shear. Early the next day, the storm reached hurricane intensity and continued to strengthen on its path toward the southern United States.

At 11:55 a.m. on Aug. 29, Hurricane Ida made landfall near New Orleans, Louisiana, as a Category 4 hurricane. At landfall, Hurricane Ida brought maximum sustained winds of 150 miles per hour and a minimum central pressure of 930 millibars, a unit for measuring atmospheric pressure in weather reporting. For nearly four hours after landfall, the storm remained a significant coastal storm surge event with intense winds.

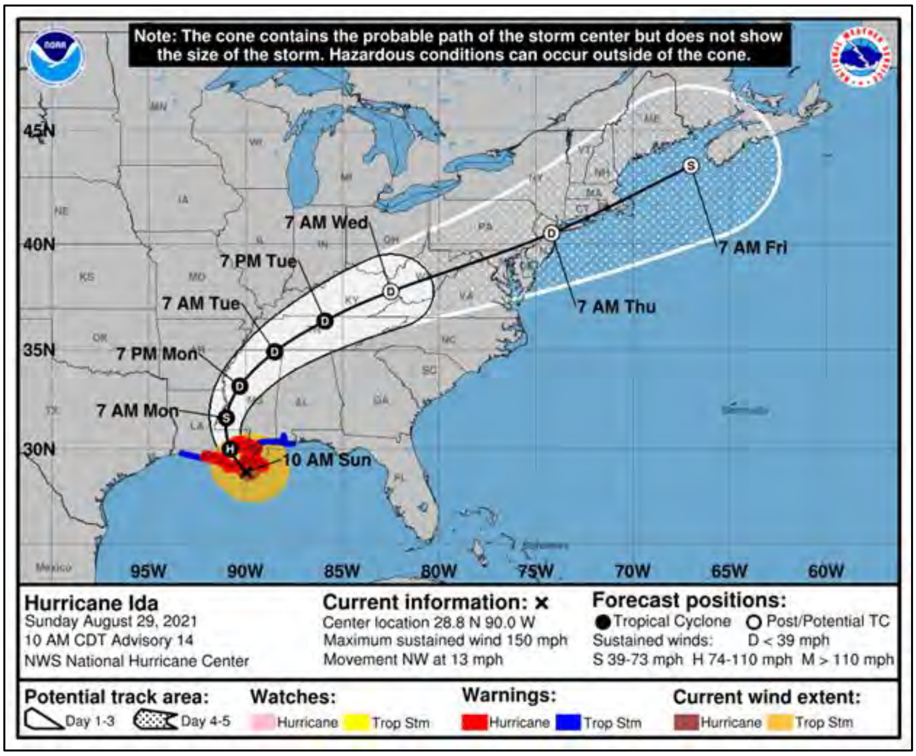

Figure 1. Hurricane Ida's projected path shortly before landfall, Aug. 29, 2021. Source: National Weather Service

After producing devastating damage in Louisiana, the storm weakened the next day, becoming a tropical depression as it moved inland and turned northeastward. By Sept. 1, the storm accelerated through the northeastern United States as a post-tropical cyclone, causing severe impacts over a large swath of the eastern part of the Northeast region. Fed by tropical moisture, the remnants of Ida delivered heavy rain, broke multiple rainfall records, and caused widespread flooding.

In the Northeast, communities were inundated; in particular, parts of Pennsylvania and New Jersey, and the New York City metropolitan area were significantly impacted. The National Weather Service's New York City office issued a "flash flood emergency" in response to severe flooding in northeastern New Jersey, followed an hour later by a similar alert in New York City Based on precipitation during this event, the recurrence interval — based on the probability an event will be equaled or exceeded in any given year — varied widely depending on location and duration. Nevertheless, many river basins received rainfall exceeding a 1 percent annual exceedance probability (AEP) event or 100-year average annual recurrence interval in a 24-hour period. For a 3-hour duration at some rainfall gage locations, the annual recurrence intervals were as high as 1000 years. Twenty-four-hour precipitation totals in the Delaware, Ramapo, Passaic, Elizabeth, Rahway, and Mamaroneck River Basins ranged from 3–12 inches. The storm also spawned multiple tornadoes throughout New Jersey and into Pennsylvania.

A week earlier, Tropical Storm Henri brought as much as 5–10 inches of rainfall to some of the same areas in the Northeast, becoming a significant contributing factor to flooding within Ida's path. The storm's extraordinarily high rainfall intensity caused many local stormwater collection systems to become temporarily overwhelmed in and around New York City and throughout Philadelphia and New Jersey. Transportation networks were severely impacted. Commuter rails, subways and interstate highways were impassable for several hours, and many cars were flooded and abandoned on area roadways.

Hurricane Ida caused 91 fatalities across nine states, 56 of which occurred in the Northeast, most due to drowning. Many areas of the South and Northeast experienced significant, costly damages, especially due to fluvial flooding. U.S. Army Corps of Engineers (USACE) projects located within these areas performed as they were designed, owing their success to past lessons learned and dedicated preparation prior to the storm's arrival. The storm event which occurred on the 16th anniversary of Hurricane Katrina, offered USACE the opportunity to reflect on lessons learned since Katrina, as well as address new challenges it is incorporating into future operations. These lessons learned and initiatives can also be applied globally to the support USACE provides partner nations under the U.S. national security framework.

Figure 2. Brig. Gen. Thomas Tickner, USACE North Atlantic Division commanding general and division engineer; Col. Matthew Luzzatto, USACE New York District Commander; and district personnel conduct damage assessments post Tropical Storm Ida, at the Green Brook Flood Risk Management Project, Middlesex, New Jersey, September 2, 2021. (U.S. Army photo)

USACE Authorizations and Partnerships: How USACE Responds to Disasters in the United States

In the United States and its territories, USACE is prepared to respond to natural and man-made disasters as part of the federal government's unified national response to disasters and emergencies. As part of its emergency management mission, USACE prioritizes saving lives, managing risk to property, and supporting immediate emergency response needs of USACE assets and projects, the Department of Defense (DoD), the Federal Emergency Management Agency (FEMA), and the federal government. During natural disasters and other emergencies, USACE can respond under its own authorities; as a component of the DoD; and as the designated lead agency in support of FEMA for its Public Works and Engineering Emergency and other essential functions.

USACE conducts its civil emergency response and recovery activities under two basic authorities: the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act); and Public Law 84-99 (Flood Control and Coastal Emergencies), as amended.[3]

Under the Stafford Act, USACE and other federal agencies work under the direction of FEMA. USACE, as the primary agency for FEMA's Public Works and Engineering Emergency Support Function, establishes responsibilities and expertise beyond USACE's primary civil works mission areas to supplement state and local efforts toward effective and immediate response. For example, when assigned a mission by FEMA in this capacity, the USACE supports with infrastructure response and recovery activities to include conducting needs assessments, debris management, providing temporary emergency power to public facilities, emergency infrastructure assessments, temporary housing, temporary roofing, critical public facilities, assisting local officials in the restorations of water and waste-water treatment systems, the demolition or stabilization of damaged structures, and other infrastructure-related technical assistance.

Under PL 84-99, *Emergency Response to Natural Disasters*, is USACE's basic authority to provide for emergency activities in support of state and local governments prior to, during and after a flood event and for repairing damage to flood risk reduction projects. Under PL 84-99, USACE can provide both emergency technical and direct assistance in response to flood and coastal storms, as well as disaster preparedness services and advanced planning measures designed to reduce the amount of damage caused by an impending disaster.

Figure 3. "Select PL 84-99 Activities." Source: USACE

Between Aug. 26 – Sept. 4, 2021, USACE used both authorities during its response to Hurricane Ida. FEMA activated USACE under the Stafford Act to support Public Works and Engineering solutions in Louisiana, where the storm made landfall. Though FEMA activated USACE for support under the Stafford Act in New Jersey and Pennsylvania, aside from providing technical assistance, there were no significant requests. However, USACE did activate five of its emergency operations centers across the Northeast region in preparation for the event.

USACE Readiness

USACE continually incorporates lessons learned from disasters to improve not only design and construction, but also operational and contingency planning. Prior to the start of each hurricane season, USACE and its partners conduct joint hurricane exercises to test command and control procedures, technical steps for responding to the next disaster, procedures for operating major structures, and to partner and synchronize efforts among federal, state, and local agencies. Besides exercising challenges to physical infrastructure, USACE devotes time and effort in protecting and testing cyber security infrastructure to ensure systems remain operable during both blue-sky conditions and emergencies.

Figure 4: Leon Skinner, U.S. Army Corps of Engineers Baltimore District, emergency management specialist, monitors the flow of sand through a sandbag filling machine Aug. 31, 2021. USACE Baltimore District provided a sandbag filling machine to the District of Columbia in coordination with DC Homeland Security and Emergency Management Agency & D.C. Mayor Muriel Bowser to ensure critical D.C. government facilities and infrastructure had extra protection ahead of Hurricane Ida. (U.S. Army photo by Nicole Strong)

In coordination with its partners and on a scheduled basis, USACE conducts routine inspections of USACE-completed flood and coastal storm risk management projects that are operated and maintained by the non-federal sponsor. Inspections are conducted jointly by engineers or technical representatives of USACE and local partners, noting any observable deficiencies to be addressed for the project to maintain its structural integrity and design capabilities to provide flood risk management to the community.

USACE relies on the public and local users of its navigation infrastructure, such as harbormasters and the U.S. Coast Guard, to report any changes in the conditions of federal navigation projects. This allows USACE to better fund and schedule hydrographic condition surveys of channels and anchorages, as well as assess the condition of other important navigation infrastructure such as jetties and breakwaters.

Ida Preparation

In anticipation of Ida, USACE used the authority of PL 84-99 to obtain and share reliable, advance notice of potential storm impacts. This assisted in the accurate prediction of potential consequences as Ida passed through the region. Assessing and communicating disaster risks to establish effective courses of action and shared expectations for likely outcomes, both internal and external to USACE, is an essential element of disaster preparedness and a good business practice.

When a major storm such as Ida is imminent, USACE identifies and pre-positions available resources to enable a timely and efficient response to potential requirements. Using lessons learned from previous disasters, USACE's response role started with extensive pre-storm preparations (two to four days before the storm's arrival depending on predicted impact), including internal assessment and management of existing projects, the activation of emergency operations centers, and coordination with other federal and non-federal agencies. USACE North Atlantic Division economists estimate the agency's existing flood risk reduction projects, throughout Pennsylvania, New Jersey and New York, prevented approximately $700 million in damages to residential, commercial, and industrial properties, as well as governmental critical infrastructure.

USACE districts began coordination with FEMA, U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA) as facilitated by the National Water Center (NWC) on Aug. 27 to synchronize inundation mapping and modeling efforts for possible impacted coastlines across the federal government. The districts and the Mapping, Modeling and Consequences (MMC) Production Center used the Corps Water Management System (CWMS) as the automated information system to support USACE's water management mission during this event. The CWMS integrates real-time stream gages and the National Weather Service (NWS) quantitative precipitation forecasts, database storage and flow forecasting, to support reservoir operation, determine flood risk areas and magnitude, and estimate consequences through damage analysis.

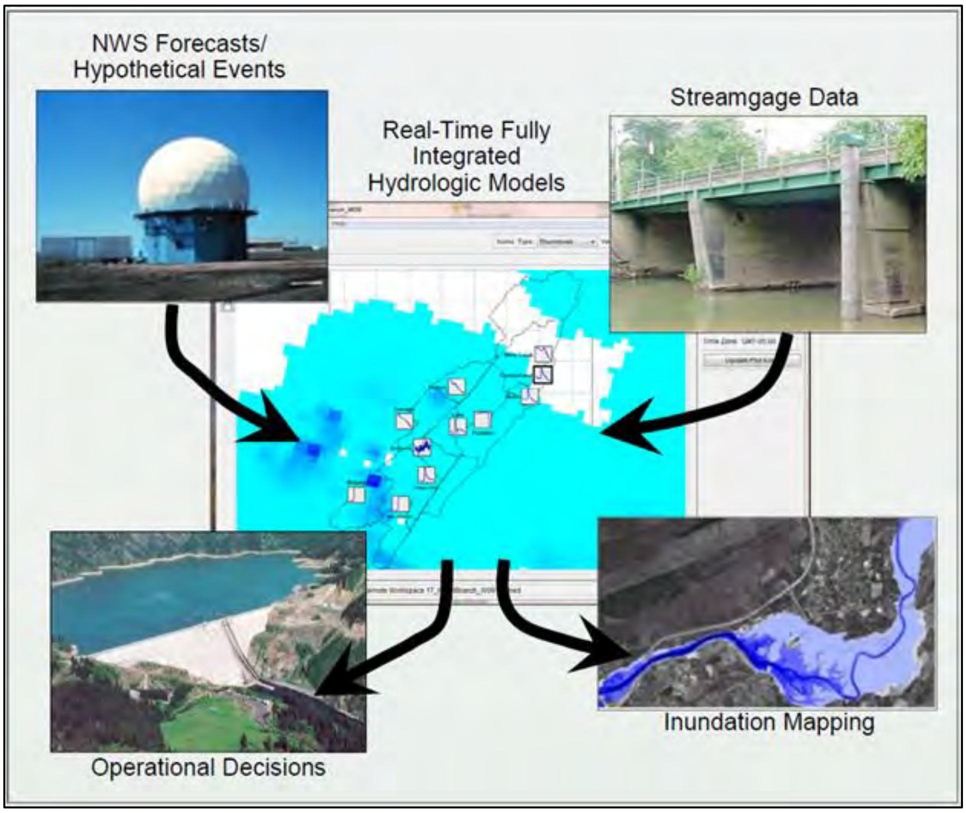

Figure 5. USACE Corps Water Management System (CWMS) real-time water management automated information

system. Source: USACE

The districts, following their water control manuals, managed reservoir water pool levels before the event. For example, approximately three days before the storm reached the Northeast region, water control personnel at the Engineering & Construction Division/Operations Division in Philadelphia District began operations at the Blue Marsh Lake and Dam. This project operates water supply, water quality control, low flow augmentation in the Schuylkill River, and salinity repulsion in the Delaware River Estuary. It also aids in flood control along the Tulpehocken Creek and the Schuylkill River. Through dam water releases for water storage maximization, the projects decreased the peak flows downstream of the dams during and after the event, resulting in an overall reduction to flood levels and adverse consequences. In this example, Blue Marsh Lake and Dam used 53 percent of its flood control storage. Other projects in the region, the F. E. Walter and Beltzville Dams, used 44 percent and 20 percent, respectively. All projects followed authorized water control plans and performed as expected.

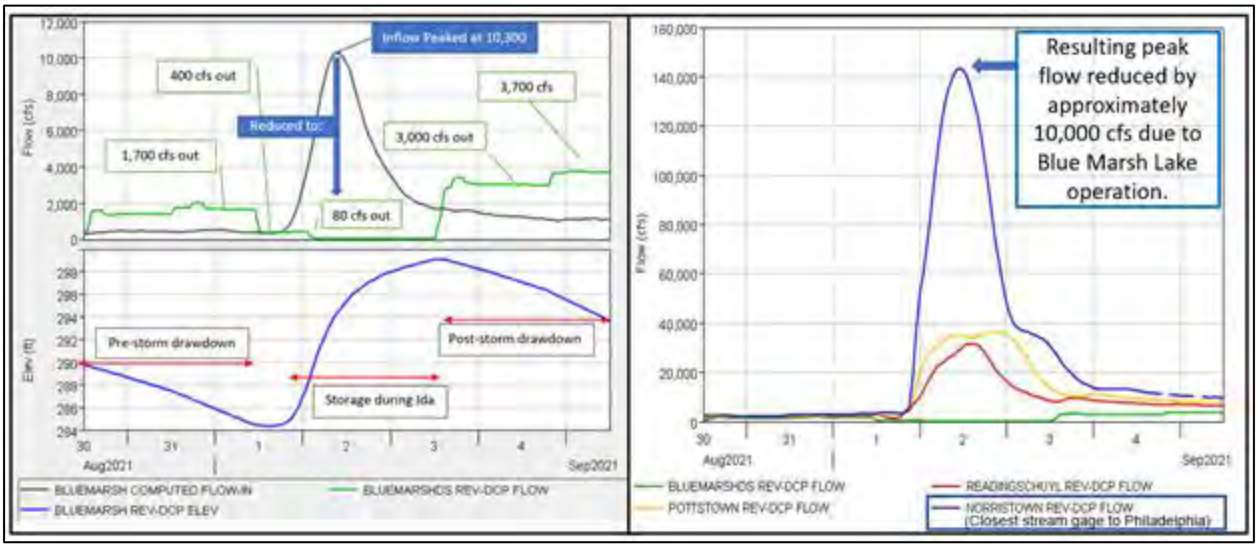

Figure 6. USACE Philadelphia District Blue Marsh Lake Dam operation between Aug. 30 and Sept. 5, 2021. The left graph shows the inflow to the dam reservoir (purple) and the reduced outflow from the dam (green) due to pre-storm reservoir drawdown. Source: USACE

Using authorities under PL 84-99, district emergency operations centers within the North Atlantic Division were activated to provide technical assistance to state and local partners and to ensure readiness. Flood-fighting materials, such as sandbags, rolls of polyethylene plastic and alternate flood-fighting materials, were placed on standby, prepositioned and ultimately released as needed. For example, as the storm advanced toward the Northeast, USACE preemptively installed stop-log closures at a project in York, Pennsylvania, which was under construction for ongoing rehabilitation, reducing flood risk to communities along nearby Codorus Creek.

Figure 7. USACE Baltimore District team members and contractors install road closures Sept 1, 2021, in York, Pennsylvania, ahead of Ida's arrival. (U.S. Army photo)

Ida Response

In response to Hurricane Ida, USACE deployed more than 2,000 individuals to work on the ground with impacted partners across the nation, with nearly 500 more providing response support and coordination from home stations.

Following Ida in the Northeast, post-storm evaluations conducted with federal and non-federal partners showed some damages were incurred to a small number of USACE's flood risk management (FRM) project elements and required an investment in repairs. USACE personnel from the Baltimore, Philadelphia, and New York districts, along with project officials, deployed to inspect impacted projects. As a result, the team identified $2 million in repairs to FRM projects in Elizabeth, Bound Brook, and Paterson, New Jersey, as well as in Allentown, Pennsylvania. As of this writing, project information reports to facilitate repairs are being evaluated for proposed funding and final estimates for engineering and repair are being prepared for work expected in this construction season.

Under the PL 84-99 authority, USACE used $2.6 million to prepare flood projects and reduce damages from Hurricane Ida. These funds also enabled USACE to inspect projects after the storm and conduct any needed short-term repairs.

Overall, USACE received approximately 30 FEMA Mission Assignments associated with Hurricane Ida emergency response efforts to include national and regional activations, temporary power, temporary roofing, temporary housing planning and group site design, infrastructure assessment planning, debris removal oversight, unwatering, critical public facilities, high-water support, field operations, public assistance, and individual assistance totaling more than $350 million

Domestic Coastal Storm and Flood Risk Management

USACE planning for coastal storm and flood risk management follows a disciplined approach to manage and reduce risk from waves, erosion and inundation that considers a full array of risk management measures. These include:

- policy and programmatic measures, such as coastal zone and flood plain management provisions which are typically the responsibility of state and local governments.
- hard structural measures, such as levees, floodwalls, breakwaters and storm surge barriers.
- soft structural measures, like beach berms and dunes.
- nonstructural measures, such as flood warning, floodproofing and elevation.
- natural and nature-based features, such as living shorelines and oyster or coral reefs.

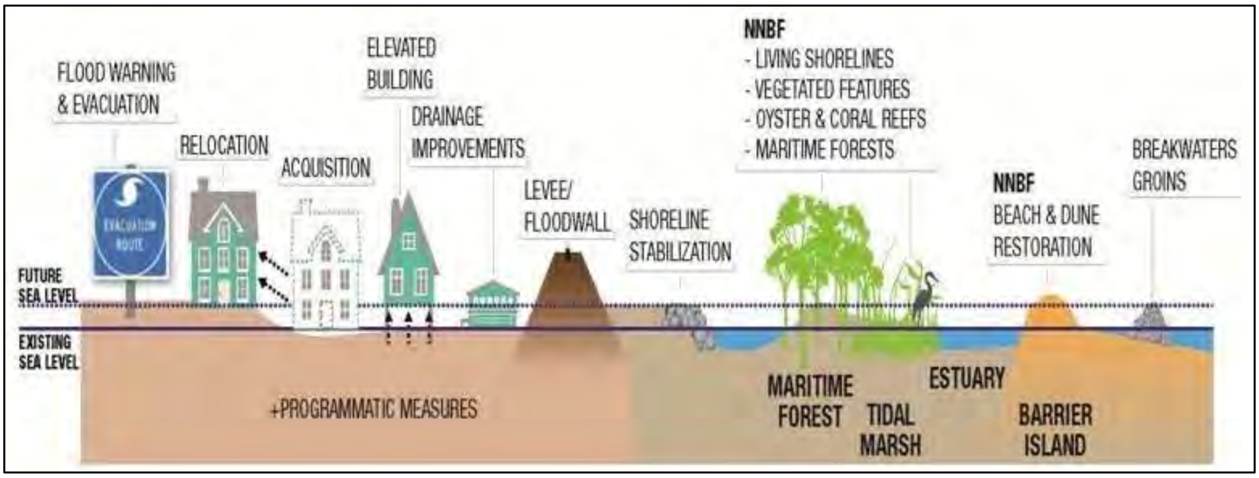

Figure 8. This figure illustrates the full array of coastal storm risk management measures addressed by the 2015 North Atlantic Coast Comprehensive Study, which was built on lessons learned from Hurricane Sandy. Source: USACE National Planning Center of Expertise for Coastal Storm Risk Management

Depending on the nature of the flood risk, USACE planners, engineers, and scientists, in concert with our non-federal partners, weave together these measures to develop alternatives that provide a systems approach to coastal and flood risk management. The implementation of a systems approach to reduce damages and better manage risk to people, structures, and public infrastructure due to fluvial and coastal storms, demonstrates the service provided to the nation by the USACE Flood Risk Management Program.

Flood and coastal storm risk management in the United States involves all levels of government and requires shared responsibility among communities, stakeholders, tribal nations, and local, state, and multiple federal government agencies. U.S. federal agencies have distinct authorities that intersect in complex ways and work in concert through incentives, preventive measures, and recovery support. The USACE Planning Centers of Expertise for Coastal Storm Risk Management and Flood Risk Management have key roles in developing new risk management efforts and supporting them throughout their life cycle.

USACE strongly supports the state-led Silver Jackets program. Silver Jackets combine diverse agencies and tools and work with local emergency responders to enhance preparedness and manage risk and damage before events occur and to support response and recovery efforts post-disaster. State-led Silver Jackets teams exist in all states and several territories, bringing together multiple state, federal, and sometimes tribal and local agencies to learn from one another in reducing risk from floods and sometimes other natural disasters. By applying shared knowledge, the teams enhance preparedness, mitigation and response and recovery efforts when such events occur. Resources for team activities come through individual programs of each agency, within the constraints of available budgets. No single agency has all the answers but leveraging multiple programs and perspectives can provide a cohesive solution.

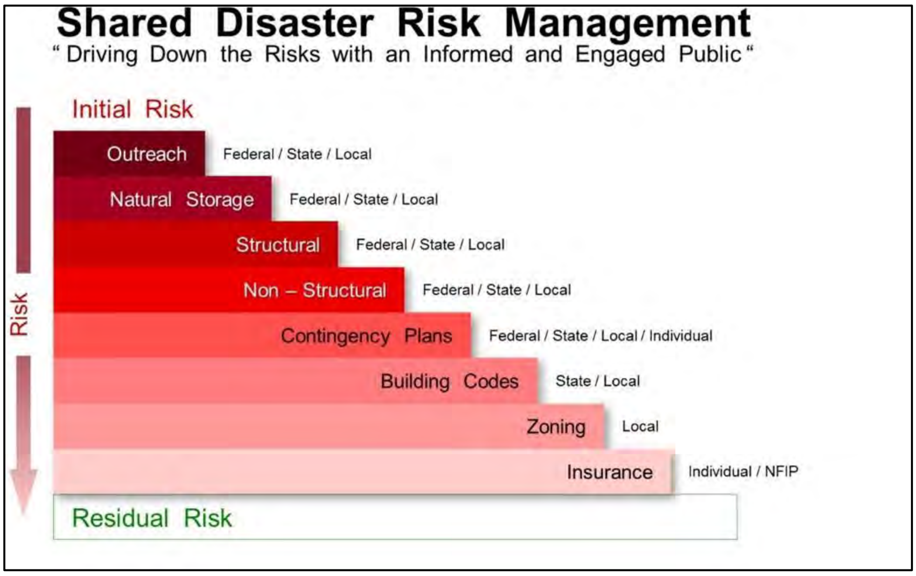

Figure 9. "Shared Disaster Risk Management." Source: USACE

USACE's flood and coastal storm risk management mission areas address flood risk management through a lens of resilience that cycles through preparation for flood and coastal storm events, absorbing impacts, recovery, and adaptation.

Figure 10. "Resilience Cycles." Source: USACE CECW-EC Pamphlet No. 1100-1-5, Dec. 1, 2020.

USACE works with partners to communicate current and future flood risk in a consistent and proactive manner. Studies for new projects are typically cost-shared with non-federal partners whose input to the study goals and intended outcomes is critical to a successful project. Other USACE programs, such as the Tribal Partnership Program, Planning Assistance to States, and the Floodplain Management Services Program, facilitate USACE engagement at the community level and can be tools for providing flood risk management solutions to communities that have been historically underserved. Additionally, the National Hurricane Program is a multi-federal agency program that falls within the Floodplain Management Services Program. It enables USACE to provide hurricane evacuation studies and tools critical to informing emergency management decisions in advance of impacts from tropical cyclones.

Addressing the Future: Incorporating Climate Change into Future Responses

In February 2022 the U.S. Army published its first Climate Strategy which states the immediate hazards associated with climate change include higher temperatures, changing precipitation patterns, and more frequent, intense, unpredictable, and extreme weather.[4] USACE acknowledges sea levels are rising, and as such coastal storms can be of even greater depth and extent when they do occur.[5] This is also one of the main takeaways of the *2022 Sea Level Rise Technical Report*, which states "sea level along the U.S. coastline is projected to rise, on average, 10–12 inches (0.25 - 0.30 meters) in the next 30 years[6]." These situations present opposing challenges, but all may increase competition for scarce resources and demand for timely humanitarian aid and disaster response.

The secondary impacts of climate and water-related disasters could be even worse. Chief among them is an increased risk of armed conflict in places where established social orders and populations are disrupted. Taken together, climate hazards will result in economic and social instability, fewer goods to meet basic needs, and a less secure world. The U.S. Army and USACE must act decisively and urgently — in coordination with partners and stakeholders at all levels domestically and internationally — to address the risks associated with these effects.

USACE Climate Posturing

Climate change and variability, both observed and as projected for the future, are important drivers of change and have significant impact on how the U.S. manages its national water resources and infrastructure. USACE policy integrates climate change adaptation planning into its missions, operations, programs, and projects and is working on implementable action to tackle climate change in consultation with external and other federal science agency experts across the nation.

As a result of these planning efforts, several tools have been developed to provide qualitative and quantitative assessments of climate change to further understand the vulnerabilities of communities across the nation. The tools enable decision-makers, planners, and engineers to manage the potential impacts and mitigate for future climate change. The result is USACE projects and infrastructure with a higher performance that is adaptable, robust, and resilient, while reducing the risk of adverse consequences to people and goods.

- **Sea-Level Change Curve Calculator**[7] **and Sea Level Tracker**[8]. These tools provide quantitative analysis of both past (observed) changes as well as three potential future (projected) sea level change scenarios projected to the end of a project's lifecycle and to a 100-year planning horizon. They support the assessment of navigation and coastal storm flood risk reduction studies and projects and determine the sensitivity of coastal community areas to climate change. The tools also support USACE in formulating, evaluating, engineering, designing, operating and maintaining projects. As a result, the coastal projects are resilient but also can be efficiently and effectively adapted to increases in frequency and severity of storm events.

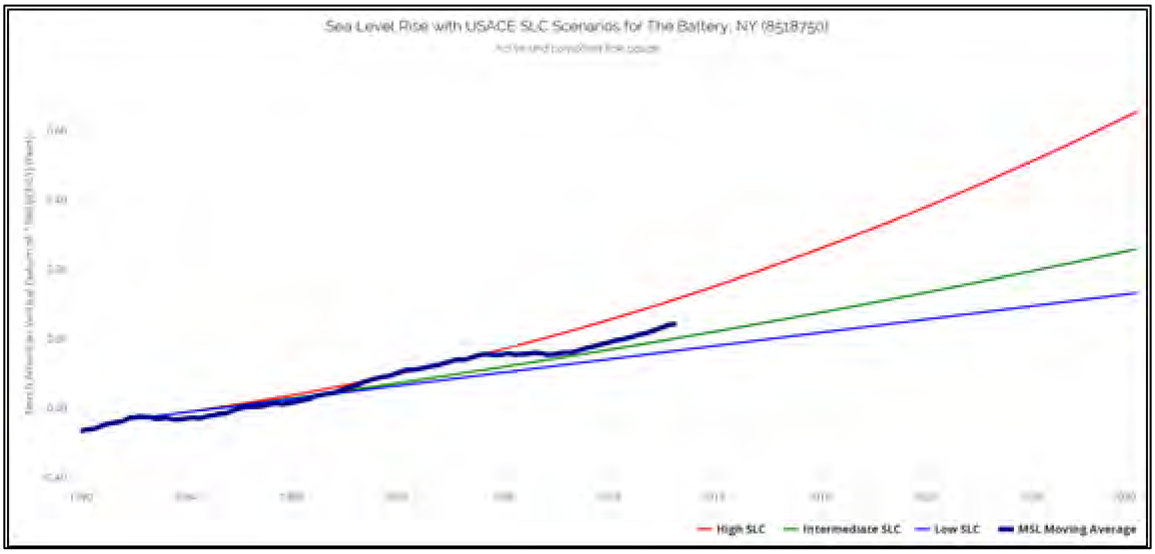

Figure 11. Sea levels change since 1990 and USACE Climate Change 2030 Predictions Scenarios for The Battery, New York. (NOAA Tidal Gage #8518750).

- **Non-stationarity Detection Tool[9].** Recent scientific evidence shows in some places climate change and human modifications to land use and land cover are resulting in changes to watershed response over time. This undermines the assumption of stationary hydrologic conditions. The Non-stationarity Detection (NSD) Tool enables USACE planning and engineering staff to apply a series of statistical tests to assess the stationarity of streamflow data.
- **Climate Hydrology Assessment Tool[10].** This tool provides qualitative analysis of both past (observed) changes as well as potential future (projected) changes to relevant hydrologic elements of proposed studies and projects. The tool allows engineers to analyze state-of-the-art hydrologic and climate model information, such as ranges and trends in climate-modeled annual maximum monthly streamflow at the watershed scale.

By developing and incorporating these types of tools, USACE better engages partners and communities on risk-informed decision making by cultivating a better understanding of risk, residual risk, and individual responsibility. Residents play a large role in a flood system's vulnerability. With each passing storm, open and transparent communication is important, because complacency among residents can become a system's greatest vulnerability. USACE works closely with communities and residents to provide necessary information and empower individuals and communities to make risk-informed decisions.

International Efforts

While USACE plays a significant role in preparing for, responding to, and recovering from disasters taking place within the borders of the United States, it is also uniquely positioned to apply its capabilities to support our international partners with their resiliency, disaster response and recovery requirements.

USACE maintains a broad suite of technical capabilities, including engineering research and development, shared through strong partnerships with interagency, academic, and host-nation stakeholders, as well as non-governmental organizations. Through USACE's Institute for Water Resources (IWR) and the United Nations Educational, Scientific and Cultural Organization (UNESCO)-affiliated International Center for Integrated Water Resources Management (ICIWaRM), USACE engages on water-related matters with multiple levels of government, industry, international and academic partners to discuss issues such as resiliency, flood risk management and climate change adaptation. This engagement leads to natural exchanges of information and lessons learned that serve to build our partner nation's capacity to improve water management practices and respond to disasters while fostering U.S. national interests and initiatives with developing partner nations.

Water security challenges pose a significant threat to local and regional stability and are sensitive to impacts from transboundary relationships, global climate change and governance practices, among other issues. Water-related challenges can greatly stress economic, political, and societal governance structures, and in certain regions, become an impetus for weakened government, rising political instability, and national security challenges (e.g., violent extremist organizations).

For example, this is evident in Africa's Lake Chad Basin, where water scarcity has triggered degradation of livelihood and stability. As Southern Africa and Madagascar also experience severe drought-related issues, USACE, working under the direction of a U.S. Department of State-led interagency coalition, has provided regional support to aid in building local capacity to manage these challenges. USACE's IWR is working with partners, like the World Bank, in supporting efforts with climate risk management and ministerial-level education. USACE is also partnering with a UNESCO-International Hydrological Program (UNESCO-IHP) effort at Kruger National Park in South Africa to plan for environmental security under threat of climate change and water supply conflicts and has provided mapping and modeling expertise in eSwatini.

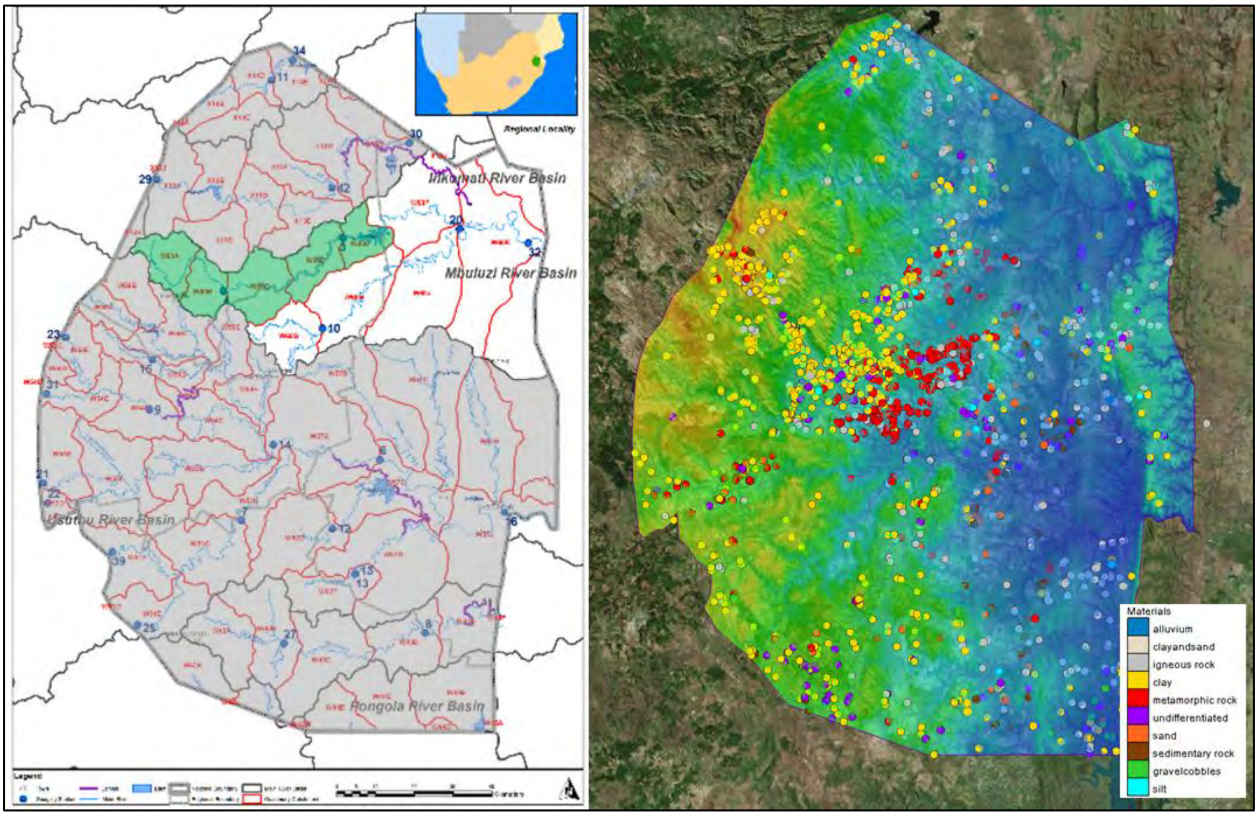

Figure 12. "Hydrology and Hydraulic Modeling (Surface and Groundwater) in eSwatini." Source: USACE Philadelphia District

USACE led the development of the Climate Risk Informed Decision Analysis (CRIDA) guidance document, which is endorsed by UNESCO-IHP and part of the United Nations Framework Convention on Climate Change's tool kit for adaptation, to mitigate water security stressors and natural disaster shocks given climate change and other future uncertainties. The CRIDA approach has been applied with partners for water and environmental security in California, Zambia, Chile, Philippines, and Thailand.

Water security challenges can also become a source of diplomatic stress and transboundary conflict. The Grand Ethiopian Renaissance Dam (GERD) in Ethiopia has stressed relationships between three U.S.-partner nations:

Ethiopia, Egypt, and Sudan. Because water problems involving water security often are not technical, engagements with stakeholders to address conflicts and facilitate shared solutions/vision geared toward interest-based exchanges for decision-making are central to the USACE water planning processes.

With a focus on technical cooperation supporting interagency and host nation partners, USACE understands shared learning is central to innovation. This is critical in addressing challenges of water security that are increasingly complex and the cause of volatility. For example, USACE maintains a technical cooperation partnership with the Ministry of Water and Transportation of the Netherlands (the Rijkswaterstaat). Working groups with experts of both agencies include the Levee Safety Partnership, Coastal and Flood Risk Working Group, and an emergency working group, which seeks to promote joint trainings and observer status during actual emergencies.

As an organization that supports defense, development, and diplomatic initiatives, USACE has gained a unique perspective and a wealth of lessons learned on water-related matters. It views water security as an instrument to build and support partnerships balancing human and environmental needs. USACE recognizes there are challenges that are not just technical, but exist within cultural, social, and political contexts.

As with domestic emergency and planning capabilities, solving water security challenges requires a coordinated approach leveraging the collective expertise of governmental, academic, non-governmental, and industry partners. While such challenges can be complex and far-reaching, collaborative solutions can support broader national and international interests. Water security and associated disaster response solutions can be an enabler to building or strengthening relationships, improving disaster response, providing humanitarian assistance, encouraging good governance, building partner capacity, and ultimately promoting stability and growth.

USACE recognizes more comprehensive risk management can only be realized when individuals and government agencies at non-federal and federal levels collectively recognize, understand, and act to manage and effectively reduce risks attributed to threats posed by fluvial flood events and coastal storms. USACE looks forward to engaging with its partners globally to continue to learn from each other and find ways to partner with others.

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SOURCES:

1. Catastrophic Hurricane Ida hits Louisiana with 150 mph winds, Yale Climate Connections online, https://yaleclimateconnections.org/2021/08/catastrophic-hurricane-ida-hits-louisiana-with-150-mph-winds/, Aug. 29, 2021.

2. National Weather Service Website.

https://www.weather.gov/lch/2021Ida#:~:text=Ida%20made%20landfall%20along%20the,by%20satellite%20and%20radar%20imagery. February 23, 2022.
3. United States Code, 2006 Edition, Supplement 4, Title 33 – Navigation and Navigable Waters, Chapter 15 – Flood Control, Section 701n - Emergency Response to Natural Disasters, January 7, 2011.
4. Department of the Army, Office of the Assistant Secretary of the Army for Installations, Energy and Environment. February 2022. United States Army Climate Strategy. Washington, DC.
5. Engineering Regulation 1100-2-8162, Global Changes: Incorporating Sea Level Change in Civil Works Programs, June 15, 2019.
6. 2022 Sea Level Rise Technical Report, Interagency Sea Level Rise and Coastal Flood Hazard and Tool Task Force, National Ocean Service online, https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html, March 2022.
7. USACE Sea-Level Change Curve Calculator (Version 2021.12). 11 Feb. 2021. https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html
8. USACE Sea-Level Tracker (Version 1.0). Dec. 2018. https://climate.sec.usace.army.mil/
9. USACE Non-Stationarity Detection Tool (Version 2.0). 3 Jun. 2021. https://climate.sec.usace.army.mil/nsd/
10. USACE Climate Hydrology Assessment Tool (Version 2.0). Oct. 2021. https://climate.sec.usace.army.mil/chat/

5. The Early Release Strategy of Dams

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INTRODUCTION

- Flood, landslide, and droughts disasters are water related disasters that are closely related in Indonesia. Our recorded hydrological data has also shown that climate and land use changes have cause Indonesia's maximum daily rainfall intensity and its related river discharges significantly increase, the difference between maximum and minimum river discharges become wider. Those changes trigger water related disaster in many regions.
- Indonesia also face the challenge of maintaining the operation of large dams. Ministry of Public Works and Housing has to work very hard to optimize our dam operation to cope with climate change. We have 230 large dams and the other 39 dams are being constructed, in which 70% of those existing are more than 20 years old. To manage these challenges, nowadays, we are working very hard to optimize intake capacity and provide additional gates to enable early release strategy of water in dam storage to secure room for storing and absorbing the coming peak discharges.

Keywords: Climate Change, Water Related Disaster, Dam Early Release Strategy

1. GENERAL WEATHER CONDITION IN INDONESIA

Indonesia is located in the tropics between the Asian Continent and the Australian Continent, between the Pacific Ocean and Indian Ocean. Indonesia is also located by the equator and is formed from islands that stretch from west to east (Aceh Province to Papua Province). These conditions cause the weather and climate in Indonesia to have high diversity. This climate diversity is also influenced by the El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), the Asian-Australian monsoon wind circulation, the Inter Tropical Convergence Zone (ITCZ) and sea surface temperature conditions.

HYDRO- METEOROLOGICAL IN INDONESIA

Beside the mentioned before challenges, Indonesia oftenly faces the problems of convectional rainfalls. According to the Agency for Meteorology, Climatology, and Geophysical, convectional rainfalls in Indonesia can be formed if they meet the following criteria:

- Sea surface temperature should be at least 26.5^o Celcius to a depth of 60 meters.
- Atmospheric conditions are unstable, allowing the formation of Cumulonimbus clouds.
- The atmosphere is relatively humid at an altitude of about 5 kilometers (≈15 thousand feet).

- Atmospheric disturbances near the earth's surface in the form of swirling winds accompanied by winds (convergence).
- Changes in wind conditions with respect to altitude are not too large. Changes in wind conditions will disrupt the progression of a thunderstorm

Furthermore, Indonesia's territory which is located around the equator, hence by nature is one of the areas that are most likely not traversed by tropical cyclone trajectories. However, nowadays there are many tropical cyclones that occurred, and have an indirect impact on weather conditions in Indonesia. The first cyclone is Durga, which appeared in the waters southwest of Bengkulu, then appeared afterwards, namely Anggrek (2010), Bakung (2014), Cempaka (2017), Dahlia (2017), and Seroja (2021).

Seroja Tropical Cylone

In April 2021, The Seroja tropical cyclone was the strongest tropical cyclone ever occurred in Indonesia and the closest reached the mainland region of East Nusa Tenggara Province. Seroja Cylone begins on April 3, 2021. The Joint Typhoon Warning Center (JTWC) issued the first warning against the Tropical Cyclone 26S on April 4 at 23.00 Central Indonesian Time. The low-pressure system slowly evolved into Category 1 Tropical Cyclone and was named Seroja by JTWC Jakarta on April 5 at 04.00 Central Indonesian Time when the cyclone was 95 km north of Rote Island. On April 6, 2021, Seroja Tropical Cyclone reached its peak where the wind speed reached 100 km / hour triggered wind currents, landslide, flood, flash floods in several areas in East Nusa Tenggara Province.
National Disaster Management Agency reported that as many as 509,604 persons were affected with 11,406 people displaced, 181 deaths, 271 injuries, 45 missing persons while 66,036 houses were reportedly damaged in in East Nusa Tenggara Province and in West Nusa Tenggara Province (as of 12 April, 23.30 Western Indonesian Time), with the following details:

- East Nusa Tenggara Province: 472,765 people affected, 11,406 displaced, 179 fatalities, 271 injured, 45 missing, and 60,703 houses damaged;
- West Nusa Tenggara Province: 36,839 people affected, 2 fatalities, and 5,333 houses damaged.

Related with climate change, our recorded hydrological data has also shown us that climate and land use changes have cause Indonesia’s maximum daily rainfall intensity and its related river discharges significantly increase, the difference between maximum and minimum river discharges become wider. Those changes trigger water related disaster in many regions.

Ministry of Public Works and Housing has to work very hard to optimize our dam operation to cope with climate change adaptation. We apply the technology of rainfall and water-level prediction to be able to more accurately determine the time of releasing dam water and in advance securing more capacity for storing excessive rainfall and absorbing the peak outflow discharges.

However, field data has shown us that most of our dams have storage capacity less than 50% of their annual inflow. It means that our dams could easily be filled in the early rainy season, left no room for absorbing peak discharges. The condition become more challenging since only a few of our dams are completed by gate in their spillway or intake for early releasing water to provide room for extensive rainfall.

2. THE DAM EARLY RELEASE STRATEGY

In order to manage these challenges, nowadays, the Ministry of Public Works and Housing are working very hard to modify dams by optimizing intake capacity and providing additional gates, to enable early release of water in dam storage to secure room for storing and absorbing the coming peak discharges. The implementation of early release strategy has been implemented on the 62 recently constructed and being constructed dams. After conducting deep analysis, not all dams require additional gate to lower down the water level during the rainy season or flood season. The attempts could be conducted by using the existing facilities such as intake gates for irrigation and micro-hydro. The other dams have been completed by gates. In this case, we could easily adjust the operation and maintenance manual to support the early release strategy. The detail dams scheme presented in the following figure:

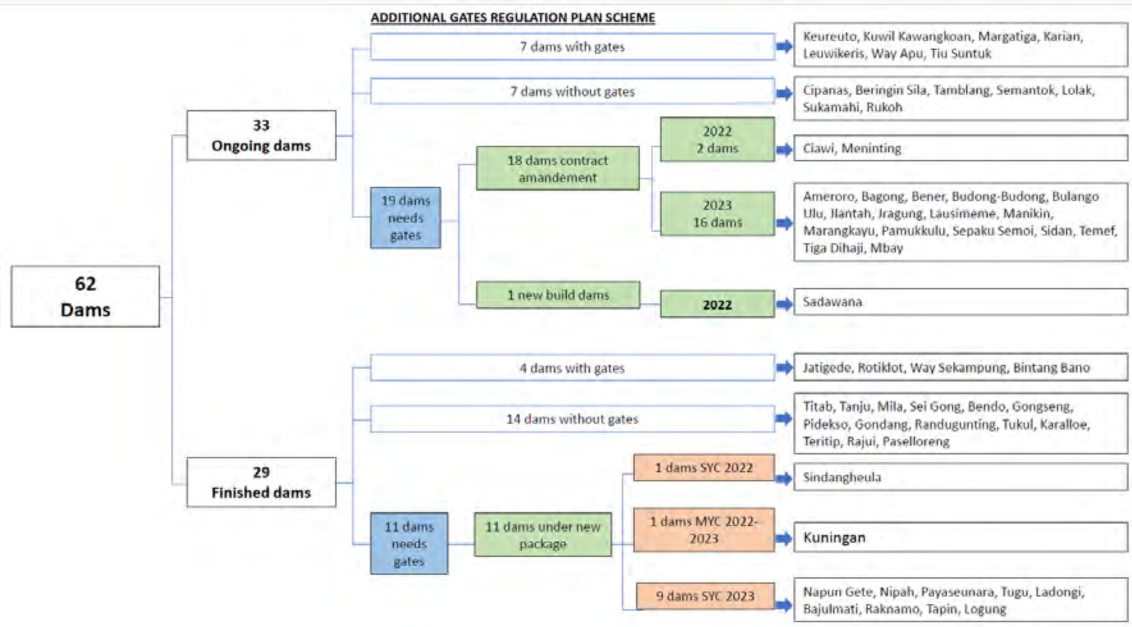

Figure 1 Adjustment of Dam's Facilities to Support Early Release Strategy

Referring to Figure 1, the result of the evaluation of 62 dams that have been and being built from 2015 to the planned completion in 2024 and 2025, the progress and strategy for the early release can be conveyed as follows:

1. There are 11 dams that have been planned as gated spillway dams, namely: Karian, Keuretuto, Tiu Sintuk, Leuwikeris, Margatiga, Kuwil Kawangkoan, Bintang Bano, Way Sekampung, Rotiklot, Way Apu and Jatigede. The initial plan of the existing gate will only be operated as an additional overflow capacity in the event of big flood discharges. For these dams, optimization of flood attenuation can be done by utilizing the existing gate as a facility for early release. Adjusting the Standard Operation Procedure for Gate Operation needs to be done by opening the gate to provide empty space in the reservoir before the flood discharge arrives. The volume of required room for flood reduction could be calculated based on the the Agency for Meteorology, Climatology,

and Geophysical early warning that regularly issued at least 7 to 3 days before the peak flood. When the flood comes, the gate must be closed to minimize the flood discharge that flows to the downstream.

2. For dams those have been planned with a spillway without gate, it is necessary to add a gate to support the early release strategy. This case covering 16 dams, i.e. Budong-Budong, Bulango Ulu, Meninting, Bagong, Sepaku Semoi, Lausimeme, Ameroro, Ciawi, Sadawarna, Tapin, Napungete, Marangkayu, Tiga Dihaji, Bener, Tukul and Sindang Heula. Currently there are 3 dams those are being constructed by adding Early Release Gate system, namely: Sindang Heula, Sadawarna and Sepaku Semoi.
3. There are 32 dams without gate on their spillway, but have outlet facilities (intake, microhydro, emergency release) with sufficient capacity to support the early release strategy. Dams included in this group are: Jragung, Manikin, Cipanas, Rukoh, Jlantah, Pamukkulu, Bendo, Sukamahi, Lolak, Semantok, Banyan Sila, Paselloreng, Kuningan, Bendo, Karalloe, Tugu, Gongseng, Ladongi, Pidekso, Randugunting , Sei Gong, Gondang, Mila, Logung, Raknamo, Tanju, Payaseunara, Barnacles, Rajui, Bajulmati, Nipah, Temef and Titab. Efforts to adjust the Outlet Facility Operation Manual are needed to make them could be also be used to provide room for flood peak reduction. After the peak flood passes, the operation of the outlet facility is returned to normal operation to fulfill the service.
4. Two dams those have relatively small reservoirs (± 3 million m^3), hence, they cannot be relied upon to help reduce peak floods, they are Sidan and Tamblang.
5. As figures, the benefits obtained from the implementation of the early release strategy for dams those being built:
   a) Sindang Heula Dam can reduce the peak discharge of flood for return period of 50 years from 196.5 m^3/s to 52 m^3/s, so it can help minimize flooding in Serang City.
   b) Sadawarna Dam will reduce the peak discharge for return period of 25 years from 536 m^3/s to 202 m^3/s, and help reducing flood in Subang and Karawang districs.
   c) Lausimeme Dam can meet the target of the flood control scheme in Medan City, with the allowable flood discharge of 320 m^3/s from the initial discharge of 479 m^3/s.
   d) Bulango Ulu Dam is able to help reduce the peak flood discharge flowing to Gorontalo City from 587 m^3/s to 100 m^3/s.
   e) Bener Dam can help to meet the flood control target at Kulon Progo International Airport with an allowable flow discharge of Q_{100th} = 219 m^3/s from an initial discharge of 620 m^3/s.
   f) Sepaku Semoi Dam will help to reduce the peak of flood in the Nusantara New Capital Region from Q_{100th} = 226 m^3/s to 150 m^3/s.

3. EXAMPLE OF DETAIL DAM MODIFICATION

One example of detail evaluation, the need for additional Early Release Gates and adjustment of Operational Manual for flood control is implemented on Sadawarna Dam. General results of the modification on Sadawarna Dam can be presented as follows:

a) Annual floods always occur in Pamanukan City, Subang Regency due to the overflow of the Cipunegara River which is located at the downstream of the Sadawarna Dam.
b) Sadawarna Dam, which is planned for completion in 2022, has a height of 40 meters and a storage volume of about 71 million m^3, which is expected to help reduce flood in Pamanukan City. The type of spillway is planned to be un-gated type, and is equipped with an intake facilities for service with a total flow capacity of ± 12.8 m^3/s.
c) The maximum capacity of Cipunegara River each in Pamanukan City is 202 m^3/s, while the inflow discharge for the 25-year return period is 536 m^3/s.
d) Based on the results of the reservoir routing calculations, Sadawarna Dam has been able to reduce the peak flood discharge from Q25th = 536 m^3/s to 357 m^3/s. However, this discharge reduction is still greater than the capacity of the existing river channel (202 m^3/s) capacity.
e) Early release strategy are needed by lowering the water level as high as 3 meter, to provide room for absorbing the peak discharge outflow for the 25-year return period < 202 m^3/s.
f) To aim that target, it is needed to lower the water level as high as 3 meters during the rainy season with an average inflow discharge of 33 m^3/s, water volume ± 2 million m^3, and the time period that can be used to lower the water level is less than 7 days. Based on these data, the existing intake capacity is not able to lower the water level during the rainy season. To solve this condition, additional gate with dimensions of 3.5 meter x 3 meter is needed.
g) Currently, an additional Early Release Gate is being built outside of the existing spillway system and it is expected could optimize the function of Sadawarna Dam to minimize the potential flood in Pamanukan City.
h) Figures of dam layout, spillway modification, inflow and outflow hydrographs in condition with and without gates are presented in the following pictures.

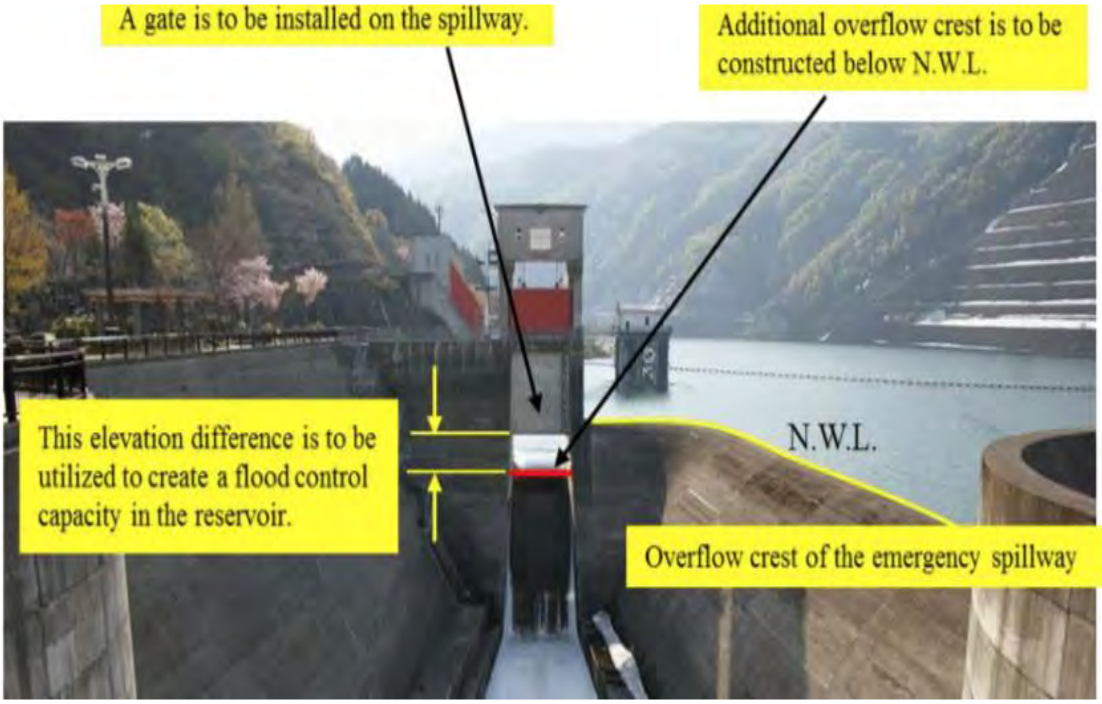

Figure 2a General Layout

Figure 2b General Layout

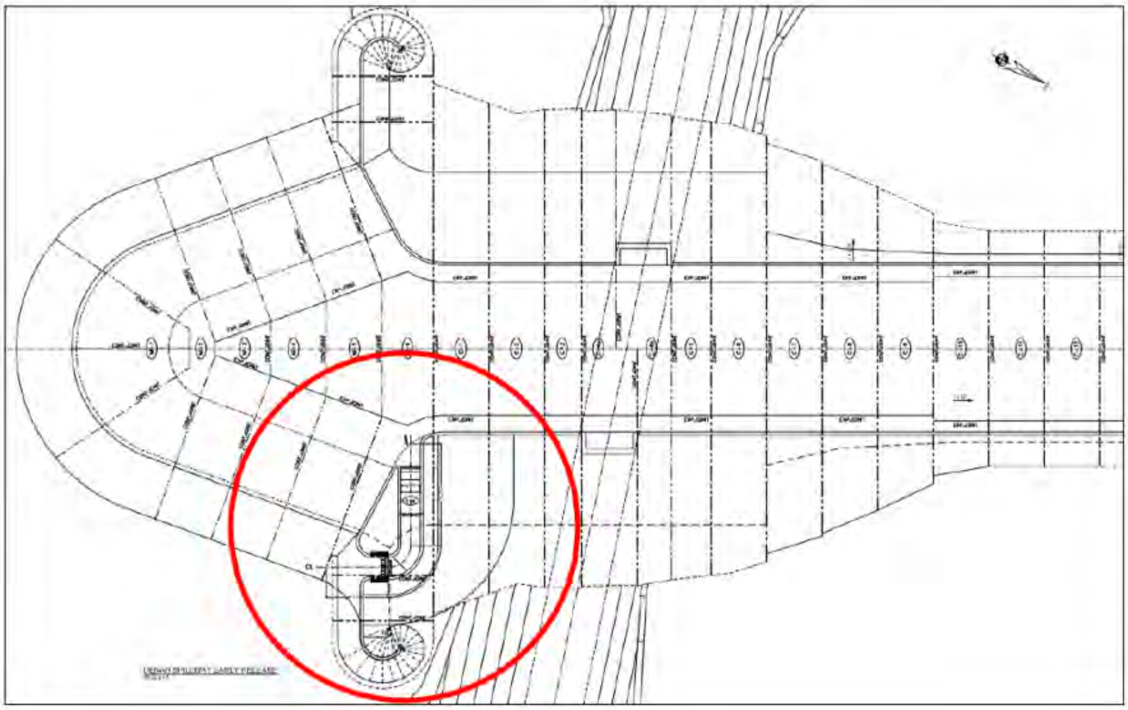

Figure 3a Detail of Additional Gate

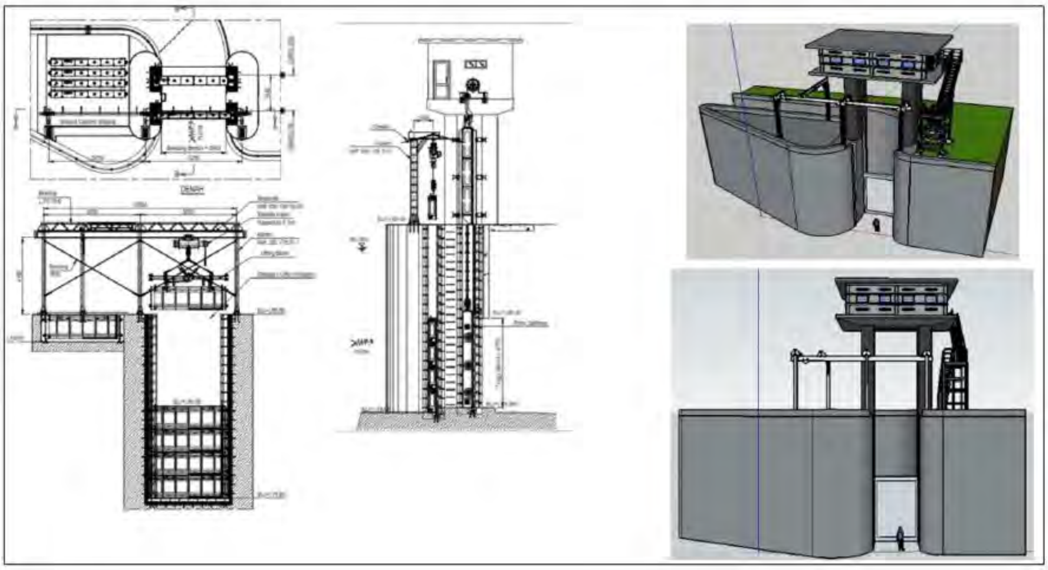

Figure 3b Detail of Additional Gate

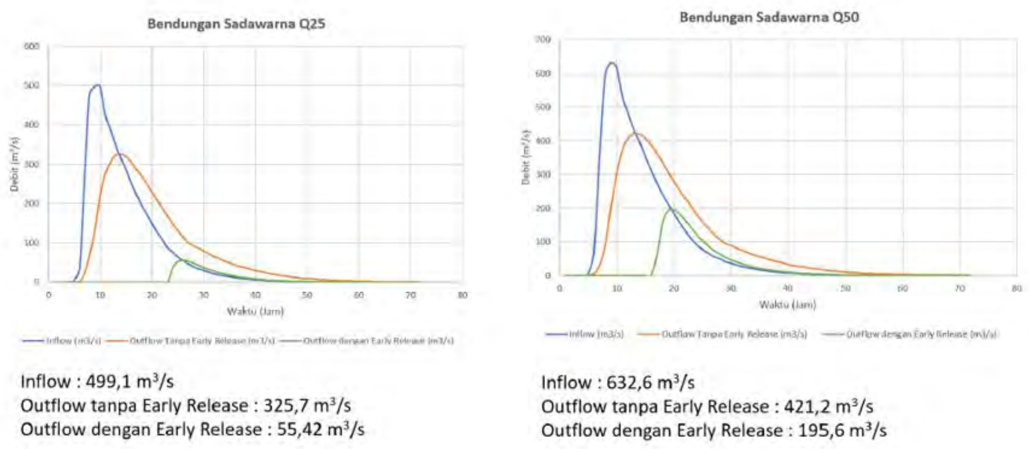

Figure 4a and 4b Inflow and Outflow Hydrograph for Q_{25th} and Q_{50th}

4. CLOSURE

To support the early release strategy and making the dam can optimally functioned in flood control, it is necessary to optimize the utilization of rainfall prediction from the Agency for Meteorology, Climatology, and Geophysical. Information on rain predictions from the Agency for Meteorology, Climatology, and Geophysical should regulargy be released within 7 days or at least 3 days before the peak of the heavy rain. This warning will be used as the starting time for the implementation of early release strategy on dams.

6. Rainfall in Zhengzhou, Henan, China in July 2021

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Summary

From July 17th to 23rd, 2021, the central Chinese province of Henan was hit by a violent rainstorm rarely seen in history, and at least eight cities in Henan were highly affected by the catastrophic flooding; Zhengzhou, Xinxiang, Pingdingshan, Zhumadian, Luoyang, Hebi, and Luohe. Among them, Zhengzhou, the capital of Henan Province, suffered most of the casualties and property damage. Thanks to the growing rate of internet access around China and increasing influence of social media across the globe, countless pictures and videos illustrating the devastation were uploaded and circulated by netizens while the rainfall was still ongoing. On the other hand, because of news articles written by professional journalists and private but detailed statements made by victims, their families or bystanders witnessing the rainfall, netizens cast doubts on the number of casualties disclosed by the Henan provincial government. On August 2nd, the State Council, China's chief administrative authority, announced that they would send an investigation team to Zhengzhou to examine the provincial government's management of the disaster. In January 2022, a 46-page report entitled "Investigation Report on 7.20 Extreme-heavy Rainstorm Disaster in Zhengzhou, Henan" (hereafter, the Investigation Report) was released online.[1] The present article takes a close look at the Investigation Report, with an aim to finding out whether the casualties and property loss during the Henan floods are the consequence of a natural or of a man-made disaster. It concludes that the floods were an extreme unprecedented natural disaster in which a certain degree of damage was unavoidable. Nonetheless, with advances in weather forecasting and monitoring techniques, some damage, including casualties, could have been prevented. The article suggests that it is imperative for the Chinese government to work with international communities with regard to disaster risk reduction, disaster response as well as recovery so as to increase resilience and build back better, since there are no boundaries for climate change issues affecting human lives, and, more importantly, these issues have to be addressed and resolved by all mankind as soon as possible. Last but not least, the article cautions that the government itself might be rendered ineffective by natural or man-made disaster and might also be inexperienced as a result of having no established best practice to follow. Consequently, citizens themselves should increase their awareness of the importance of self- and mutual help in disaster response, which is crucial for disaster risk reduction.

1. Once-in-a-thousand-year flood

When one talks about natural disasters in the Central Plain, the lower and middle reaches of the Yellow River, they are usually related to either droughts or shortage of water. Floods in northern cities lying on the banks of the Yellow River decreased with the overflowing problem of the Yellow River having been managed successfully in recent years. Probably this is one of the reasons that people in Henan, which sits on the southern bank of the Yellow River, did not

[1] Investigation Report on 7.20 Extreme-heavy Rainstorm Disaster in Zhengzhou, Henan (Henan Zhengzhou "7.20" teda bayou zaihai diaocha baogao), published in January 2022 by Disaster Investigation Team of the State Council. https://www.mem.gov.cn/gk/sgcc/tbzdsgdcbg/202201/P020220121639049697767.pdf, accessed on May 31, 2022.

anticipate that the rain that had started sporadically on July 14[2] would eventually turn into a huge disaster that would challenge their cities' disaster tolerance.

As reported by Sohu News, one of the most widely-read news sites on July 21, the rainfall mainly occurred in Jiaozuo, Xinxiang, Hebi and Anyang, northern cities of Henan. It moved south to Zhengzhou from the 19th to the 20th. Between the 21st and 22nd, it moved north again and gradually weakened and finally ended on the 23rd. The precipitation in Zhengzhou was equivalent to the city's annual rainfall, reaching 201.9 mm in an hour (4-5pm, July 20th), 552.5 mm (from 8pm July 19th to 8pm July 20th) in a single day, and 617.1 mm in three days (July 17th-July 20th). Before it moved northward, the total rainfall reached the equivalent of a whole year's worth of water on the city in a 72-hour period.[3] The estimated return period of the total rainfall, 1000 years, may not be accurate since the existing scientific record of precipitation can only be traced back to 1951 when the local Meteorological service was established. However, considering the hourly and daily amount of precipitation, Zhengzhou's rainfall in July 2021 could be called extreme.

The rainfall was not only unusually strong but lasted extremely long as well. Meteorological data suggest that the typhoon "Fireworks" (*yianhua* in Chinese), which was 1000 kilometers away at the time, contributed to the severity of the event. A large amount of water vapor was transported from the sea to the land by easterly winds and gathered into rain clouds guided by "Firework" and the subtropical high airflow. After the easterly airflow encountered the Taihang Mountain and the Funiu Mountain in Henan, it converged and uplifted in front of the mountains. The terrain further contributed to the unusually strong and concentrated rainfall. In addition, during the precipitation process, meso- and small-scale convection developed repeatedly in front of Funiu Mountain and moved toward Zhengzhou, forming "training",[4] which eventually led to intense and long-lasting precipitation. Finally, the atmospheric circulation was sufficiently stable to allow the rains to continue uninterrupted. They only stopped after the typhoon "Fireworks" was much closer, the atmospheric circulation consequently altered, and the source of water vapor cut off.[5]

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[2] Cover story "Rare rainfall in northern cities" (*Beifang chengshi hanjian bayou* in Chinese) of *Sanlian Lifeweek Magazine*, Vol.31, 2021 (*Sanlian shenghuo zhoukan* in Chinese), citing information published by Zhengzhou Meteorology Service on Weibo, reports that thunder and lightning and local rainfall began to appear in Zhengzhou City and nearby counties from July 14, while interviewees' memory of the start of the rain concentrated on July 16 and 17.

[3] Data collected from https://www.sohu.com/a/478692391_161795, originally published by Zhengzhou Meteorology Service, accessed on May 14, 2022.

[4] In meteorology, 'training' denotes repeated areas of rain, typically associated with thunderstorms, that move over the same region in a relatively short period of time. (National Oceanic and Atmospheric Administration's National Weather Service, Glossary)
https://w1.weather.gov/glossary/index.php?letter=t, accessed on May 31, 2022.

[5] Based on 1) "Interpretation: How big is the rain and how long will it last" (Jiedu: Yu daodi duo da? Haiyao xia duo jiu?) from Henan Meteorology Service (April 28, 2022), http://ha.cma.gov.cn/xwzx/qxyw/202107/t20210721_3552984.html, accessed on May 31, 2022.
2) "Where did the rainfall come from? Why is it so strong" (Zheci bayou zenme lai de? Weishenme zheme qiang) from *Liaosheng Evening* (Liaosheng wanbao, July 22, 2021),
http://epaper.lnd.com.cn/lswbepaper/pc/att/202107/22/5f583341-5981-4dc2-9e00-70a99a134209.pdf, accessed on May 31, 2022.

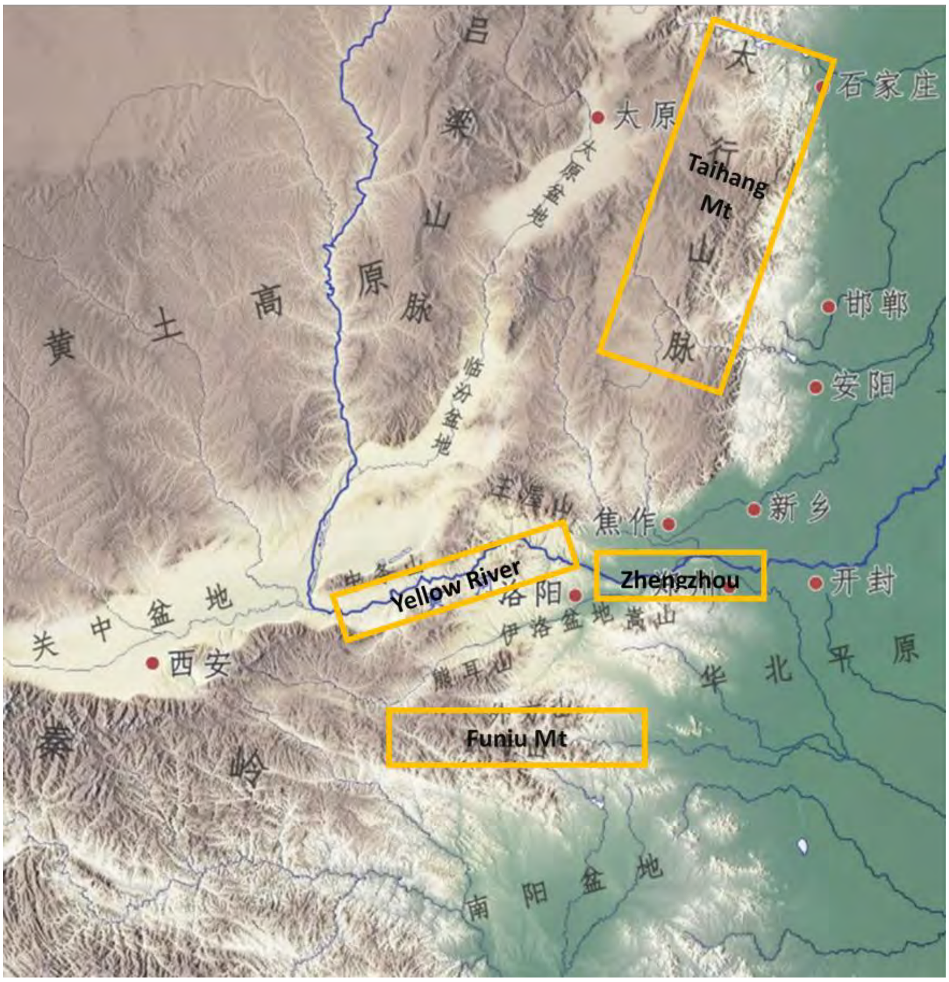

Figure 1: Map of the locations of Taihang Mt, Funiu Mt and Zhengzhou

It is worth mentioning that the Investigation Report published five months after the rainfall and written by a central government-organized team of officials and experts from the Ministry of Emergency Management, the Ministry of Water Resources, the Ministry of Housing and Urban Development, the Ministry of Public Security, and the Ministry of Health reached similar conclusions as those published months earlier by the meteorology service and the mass media as to the extraordinary nature of the Henan floods; that rainfall in Zhengzhou was "extremely strong and long-lasting".[6]

2. Number of casualties

While the public and the government shared a common understanding of the nature of the disaster, there was little agreement regarding the number of casualties. The first relevant report issued by the municipal government concerned the casualties resulting from the flooding of the Line 5 subway tunnel in Zhengzhou city around 6pm, July 20. As mentioned above, the hourly rainfall between 4 and 5 pm on the 20th reached 201.9 mm, breaking the previous record of 198.5 mm in Linzhuang, Henan, in 1975. After it reached its peak of the day, the rainwater continued to

[6] The Investigation Report, pp. 4-5.

inundate all areas of the city. When it overflowed into Line 5 subway tunnel, it forced the train to stop between Shakou-lu Station and Haitan-si Station. Since it was one of the busiest lines and 6 pm was the time around which people were in a hurry to get back home, hundreds of passengers were trapped in the train filled with rainwater accumulating to as high as people’s necks.

Picture 1：Passengers trapped inside the train on July 20th. Picture image is quoted from *Caixin Media*, a reputable Chinese media group based in Beijing known for investigative journalism. https://china.caixin.com/2021-07-21/101743465.html, last accessed on August 4th, 2022.

At 4 am on July 21, the official Weibo account of the Zhengzhou Municipal Party Committee Propaganda Department, "Zhengzhou fabu" (Zhengzhou release) announced that 12 people had died and 5 become injured in the subway flooding, while more than 500 had been evacuated.[7] At the press conference held in the afternoon of the same day by the Henan Province press office, the total number of casualties was modified to 25 deaths and 7 missing.[8]

Till August the 2nd, when the Central government made an announcement of setting up an investigation team to examine the floods, the Henan government had held altogether ten press conferences on flood control and disaster relief. At each of these conferences except for the ninth, the number of people dead and missing were reported. The following table shows that the final numbers of flood victims went up to 302 deaths and 50 missing before the central government decided to send the investigation team to make further and detailed inquiries.

	Dead	Missing	Affected (million)	Direct economic loss (billion RMB)	Source
July 21, 2021	25	7	1.24	5.42million	1st[9]
July 23, 2021	33	8	5.54	NA	2nd[10]
July 24, 2021	58	5	9.30	81.97	3th[11]
July 25, 2021	63	5	11.45	NA	4th[12]
July 26, 2021	69	NA	12.90	71.53	5th[13]
July 27, 2021	71	NA	13.31	NA	6th[14]
July 28, 2021	73	NA	13.66	88.53	7th[15]
July 29, 2021	99	NA	13.91	90.98	8th[16]
July 30, 2021	NA	NA	NA	NA	9th[17]
August 2, 2021	302	50	14.53	114.27	10th[18]

7 Zhengzhou fabu via Weibo on July 21, 2021. Weibo is a Twitter-like social media platform.

8 Rainfall caused 25 deaths and 7 missing in Henan (Baoyu zhi Henan 25ren siwang, 7ren shilian), https://china.huanqiu.com/article/441zfVX3gdS, accessed on May 31, 2022.

9 The first press conferences on flood control and emergency management by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1709893/1709893.htm, accessed on June 4th, 2022.

10 The second press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1709895/1709895.htm, accessed on June 4th, 2022.

11 The third press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1709900/1709900.htm, accessed on June 4th, 2022.

12 The fourth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1709901/1709901.htm, accessed on June 4th, 2022.

13 The Fifth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1709902/1709902.htm, accessed on June 4th, 2022.

14 The Sixth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1710211/1710211.htm, accessed on June 4th, 2022.

15 The Seventh press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1710171/1710171.htm, accessed on June 4th, 2022.

16 The Eighth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1710342/1710342.htm, accessed on June 4th, 2022.

17 The Ninth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1710212/1710212.htm, accessed on June 4th, 2022.

18 The Tenth press conferences on flood control and disaster relief by Henan government, http://www.scio.gov.cn/xwfbh/gssxwfbh/xwfbh/henan/Document/1710343/1710343.htm, accessed on June 4th, 2022.

January, 2022	398		14.79	120.6	Investigation Report[19]

Table 2 Number of casualty and direct economic loss, data collected from the press conferences held by Henan government between July 21 and August 2 and the Investigation Report published in January 2022.

At the tenth and final press conference, the Governor of Henan, Wang Kai requested that all those attending the conference stand up and pay a moment of silence to those who had died in the disaster. It is not very common in China that officials publically pay tribute or apologize on behalf of the government. However, the Henan government's gesture of sharing compassion with its people was neither effective in assuaging people's grief over their loss nor did it improve public confidence in the government. Chinese netizens have raised questions on the number of dead and missing ever since they had been made public by the government on July 21st.

Picture 2: Participants of the tenth press conference standing in silent tribute to the victims[20]

[19] Investigation Report, p.1, 4.

[20] "The Tenth press conferences on flood control and disaster relief by Henan government; Wang Kai expressed condolences to the victims on behalf of the provincial party committee and the provincial government", reported by China Daily, August 2nd, 2021 (https://cn.chinadaily.com.cn/a/202108/02/WS6107d0bfa3101e7ce975cc66.html, accessed on July 12, 2022)

Picture 3: A photograph used by *Deutsche Welle* in reporting the disaster[21]

The search engine Google, when prompted to look up images of the Zhengzhou rainfall with keywords like "Zhengzhou shuizai, 2021" in Chinese, yields thousands of related images. To some extent, unlike the previous era, it is not the lack of information, but the overflow of information, notably those unverified ones, that has developed into a new barrier for people to find out the truth. In addition, language becomes less important when so many visual sources are available; with the help of visual sources, anyone having access to internet, with or without knowledge of Chinese language and culture, is equally capable of questioning the credibility of the number of casualties reported by the Henan government.

The Investigation Report released online in January reveals the number of casualties in Line 5 subway tunnel was 14 in comparison to 12 reported by the Henan Government in July while in the case of Jingguang Expressway, six people died while the earlier number was four.[22] Furthermore, the Investigation Report uses the word, "manbao", meaning "conceal" in Chinese, 28 times in total to describe how local officials misreported the number of casualties in the disaster. Quoting the Investigation Report, "as of September 30, 380 people died or went missing due to the disaster in Zhengzhou, of which 139 were concealed at different stages: 75 were concealed at the city level, 49 at the county level, and 15 at the township (street) level."[23]

In parallel with the release of the Investigation Report, ninety-seven officials were punished for their dereliction of

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[21] "China's Henan province reels from devastating floods" by DW news, July 23. https://www.dw.com/en/chinas-henan-province-reels-from-devastating-floods/av-58607126, accessed on May 23, 2022.
[22] One representative in charge of the Zhengzhou City Administration told The Paper (*Pengpai xinwen* in Chinese) that four were found died in the flooding of the north tunnel of Zhengzhou Jingguang Expressway on July 24, https://wap.bjd.com.cn/news/2021/07/24/135813t280.html accessed on May 23, 2022.
[23] The Investigation Report, p. 11.

duty, with their names and posts being made public.[24] Xu Liyi, Party secretary of Zhengzhou as well as top of the Zhengzhou authority was dismissed from his post and received a serious warning from the Party.[25] On the one hand, the Investigation Report serves as a conclusion to the disputes evolved throughout the process of the disaster management. On the other hand, it has not yet truly removed question marks from minds of people who are not yet convinced by the governmental explanation. Cyberspace is flooded with articles questioning the number of casualties. Some even claim that the flooding of Jingguang Expressway alone had caused six thousand deaths.[26] In contrast, hardly any online news question the government-announced number of casualties caused by floods in Germany which happened around a similar time in July 2021. International comparison might alert the Chinese government to the importance of being trusted by its people.

Doubts on the number of casualties disclosed by the government have been raised both domestically and internationally on mainly two grounds. First, a great number of photos and videos demonstrating how life-threatening the situation was were uploaded online in real-time not only via online news sites but various social media platforms as well, due to widespread use of social networking sites (SNS), such as Weibo, Wechat, and even Facebook. Visual sources, such as photographs and videos showing hundreds of people trapped within the Line 5 subway train and tunnel or hundreds of vehicles trapped at the Zhengzhou Jingguang Expressway made people wonder if there were more victims than those made known by the government. Survivors recall that their cars were instantly submerged and they barely escaped with their lives. Many claimed that the time for them to run away was no more than a few minutes.[27] As a result, people reading such articles or watching photographs and videos could not help but wonder if all others trapped inside the Jingguang Expressway were as lucky as those survivors who had abandoned their cars in time and to escape from the waters which were approaching them unexpectedly.

However, one must keep in mind that false information from the same source might spread and disseminate through SNS as widely and quickly as the truth. For example, a short video spreading online showing Zhengzhou's Xingyang Aquarium was broken through in the heavy rain and sharks escaped from the aquarium was later proved to be false.

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[24] "Henan seriously investigates and punishes those responsible for the "7.20" heavy rain disaster in Zhengzhou", http://www.hnsjct.gov.cn/sitesources/hnsjct/page_pc/jdzjzfyw/gnyw/articlee2b15f07426a4877bd89f97c43b4a756.html, accessed on May, 24, 2022.

[25] "Xu Liyi, former member of the Standing Committee of the Henan Provincial Party Committee and Secretary of the Zhengzhou Municipal Party Committee, was held accountable for the "7.20" heavy rain disaster in Zhengzhou, Henan", http://www.gov.cn/xinwen/2022-01/21/content_5669733.htm, accessed on May 24, 2022.

[26] Articles arguing six thousand had died of the tragic of Jingguang Expressway can be found here: https://ec.ltn.com.tw/article/breakingnews/3615584; https://pelicanmemo.hatenablog.com/entry/2021/07/26/130000; https://www.epochtimes.com/gb/21/8/23/n13181599.htm; https://www.rfi.fr/cn/%E4%B8%AD%E5%9B%BD/20210725-%E6%B2%B3%E5%8D%97%E6%B4%AA%E7%81%BE%E5%AE%98%E6%96%B9%E6%95%B0%E5%AD%97%E5%8D%87%E8%87%B363%E4%BA%BA%E4%BA%A1-%E9%83%91%E5%B7%9E%E7%AD%89%E5%9C%B0%E6%9C%89-%E7%88%B1%E5%9B%BD%E6%B0%91%E4%BC%97-%E5%BD%93%E8%A1%97%E9%98%BB%E6%8C%A0%E5%A4%96%E5%AA%92%E6%8A%A5%E9%81%93, accessed on May 31, 2022.

[27] Stories with titles including keywords like "Escaping from the Jingguang North Road Tunnel in Zhengzhou", "survivors" are news articles, for example. published on https://news.mydrivers.com/1/771/771619.htm, https://www.thepaper.cn/newsDetail_forward_13730147, https://www.epochtimes.com/gb/21/7/25/n13113386.htm, accessed on May 31, 2022.

A picture showing a crocodile moving in the rain was actually taken from some non-Chinese website and unconnected with the events in Zhengzhou.[28] Moreover, SNS audiences have a natural tendency to trust their visual perception and to react based on first impressions without asking what, who, where, when, how and why, which are essential to making better judgement.

Secondly, Zhengzhou's catastrophic rainfall and extreme floods elsewhere in Henan reminded people of another huge flood in Zhumadian, a city in southern Henan province in 1975. Chinese people, except for local residents and those in nearby cities, did not become aware of the so-called "75.8 Great Floods"[29] until the new millennium, because it was not at all reported by then. Even though it was gradually made public through internet sources, the number of victims in the disaster nonetheless remains controversial until today.[30] According to a senior reporter of Xinhua News Agency, Zhang Guangyou (1930 - 2008), who had a conversation with the then-Vice Premier Ji Dengkui (1923 -1988), it was the central government's decision that the disaster was not to be reported publicly.[31] Such an example of keeping information from the public has caused a distrust in Chinese people toward the government. As a result, the Chinese government will probably have to deal with a lack of credibility problem each time a new crisis occurs.

3. Natural disaster or man-made disaster?

Without question, the Henan floods were a natural disaster. However, one may wonder whether the loss of human life could have been avoided, and, if so, how much the damage and loss could have been alleviated. The answer to the first question is yes. After all, the Zhengzhou Meteorological Service had already issued a second red rainstorm warning at six in the morning of July 20th. Things would certainly have turned out very differently if the government had requested schools and enterprises other than essential services to be closed for one day or half, or advised people not to go out unnecessarily. As a matter of fact, the question of whether the Henan floods a natural or a man-made disaster has been asked and argued repeatedly in the news articles with a critical point of view produced by reputable news agencies since the disaster occurred.[32] It is worth noting that most governments have hesitations or unwillingness in publicizing unverified information in the course of implementing disaster management measures

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[28] "Urgent rumor refutation! Don't believe or spread the news about the rainstorm in Zhengzhou", *Sohu News*, July 21, 2021 (https://www.sohu.com/a/478813856_121106842, accessed on July 12, 2022.

[29] 75.8 refers to the time when the floods occurred, which was August 1975.

[30] *Epochtimes*, a news site with a strong stance against the Communist Party, claimed that the death toll could be as high as 230,000 (https://www.epochtimes.com/gb/21/11/11/n13370142.htm, accessed on May 31, 2022), while a widely-quoted number with governmental source is "more than 26,000", quoting from Baidu Baike, a Chinese version of wikipedia. https://baike.baidu.com/item/%E9%A9%BB%E9%A9%AC%E5%BA%97%E6%B0%B4%E5%BA%93%E6%BA%83%E5%9D%9D%E4%BA%8B%E4%BB%B6/6025160, accessed on May 31, 2022.

[31] Zhang Guangyou, "Witnessing 1975 Huaihe Great Floods" (Mudu 1975nian Huaihe da shuizai), YanhuangChunqiu, vol.1, 2003.

[32] For example, "Zhengzhou 7.20 floods, partly natural disaster? partly man-made disaster?", August 8th 2021, https://www.voachinese.com/a/china-zhengzhou-floods-investigation-causes-effects-politics-20210808/5994418.html, accessed May 26, 2022; "Rescue worker dead Zhengzhou Jingguang Tunnel: both a natural disaster and man-made disaster", July 23rd, 2021, https://www.dw.com/zh/%E9%84%AD%E5%B7%9E%E4%BA%AC%E5%BB%A3%E9%9A%A7%E9%81%93%E7%8E%B0%E6%AD%BB%E4%BC%A4-%E6%95%91%E9%9B%A3%E4%BA%BA%E5%93%A1%E6%98%AF%E5%A4%A9%E7%81%BD%E4%B9%9F%E6%98%AF%E4%BA%BA%E7%A6%8D/a-58605421, access on May 26, 2022.

for the following reasons: 1) information without being appropriately verified and cross-checked is not reliable and, worse, might become an "official" source of further unverified and inaccurate misinformation misleading the public; 2) the spreading of misinformation can put additional burdens on the local and central authority by causing unnecessary panic among people, which makes disaster relief activities more challenging; 3) it usually takes considerable time and resources to have information verified, updated and cross-checked. On many occasions, governments are unable to update and verify information quickly enough to have them disclosed and shared since their own function might have been impaired due to sudden-onset or concurrent disasters. Areas with great damage will become zones of "information vacuum", in which misinformation and disinformation might be created and spread.[33] For example, a zone of information vacuum appeared in the aftermath of the Great East Japan Earthquake in 2011, due to unprecedented damage caused by the disaster and the fragility of the infrastructure. One of the tasks of post-disaster management is the identification of information vacuums vacua in previous disasters so as to prevent their recurrence.[34] In regard to how to combat misinformation and disinformation, not only should the governments promote news literacy and professionalism in journalism in their societies, but, more importantly, individuals should follow a diversity of news sources, stay skeptical of what they read and watch and learn to be equipped with the skill of identifying and correcting mis- and disinformation. There are already a few projects in the U.S. in which educators and journalists work together to give students the skills they need to discern fact from fiction and identify credible information.[35]

Unfortunately, when people feel that they did not receive timely information, they are inclined to blame the government for their slowness without taking the emergency into consideration, which puts additional pressure on officials. This deepens the governments' reluctance to disclose information they have not examined. In reality, many governments have to face the following dilemma in the course of emergency and disaster management: either to provide timely yet unverified information to the public or to run the risk of being accused of not disclosing information in a timely manner. Therefore, it is a common task for many governments to work on striking a balance between meeting people's expectations of timeliness and ensuring the accuracy of disclosed information.

The Investigation Report suggests that some damages could have been avoided if the proper preparations had been undertaken and if the disaster had been well-prepared and professionally handled. Failures and problems that are identified by the investigation team are as follows: 1) responsible departments had been sluggish and impractical; 2) the emergency response was seriously delayed; 3) the response measures were inaccurate and ineffective; 4) there was a lack of unified command at critical moments; 5) there was no effective mobilization; and 6) reporting was late

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[33] Misinformation: "false information that is spread, regardless of whether there is intent to mislead." Disinformation: "deliberately misleading or biased information; manipulated narrative or facts; propaganda." Fake news: "purposefully crafted, sensational, emotionally charged, misleading or totally fabricated information that mimics the form of mainstream news". For a more detailed guide, see https://guides.lib.uw.edu/c.php?g=345925&p=7772376, accessed on September 6, 2022.

[34] Masayuki Kawasaki, "Study on 'Information Vacuum' at 2011 Great East Japan Earthquake: Toward Improvement of Disaster Risk Management", *Journal of Social Safety Science*, Vol. 17, July 2012, pp, 43-52.

[35] Established in 2008, News Literacy Project (https://newslit.org/), is a representative example showing how people in American society make efforts in raising the younger generation's skill of news literacy.

and concealed the number of deaths and missing persons.[36] Expressions like “paralyzed mind”, “low vigilance”, typical rhetoric often used within the inner circle of the Communist Party against fellow party members who are to be condemned, are repeatedly used in the Investigation Report in describing how local officials failed in their missions.

Remarkably, the Investigation Report uses “ren huo”, a Chinese word for man-made disaster, to characterize the rainfall and floods. It states that “generally, it is a natural disaster while specifically, there are man-made disasters”.[37] It must be pointed out that “ren huo” is considered a sensitive word in Chinese Communists’ rhetoric, and the word is often used with extreme caution. Thus, if “ren huo” is used in an official publication issued under the name of the central government and strictly reviewed and censored before being made public, as in the case of the Investigation Report, it means that the Chinese government not only takes the event very seriously but admits governmental mismanagement as well.

At the same time, the Investigation Report makes it clear that the Central government had fulfilled its duties in giving appropriate supervision and advice to the local government in advance. It implies that the central government should be exempted from the man-made part of the disaster. Nonetheless, while it might be true that the central government had given local authorities warnings and instructions, it is within its responsibility to supervise and control the situation. In other words, the joint liability between the two cannot be easily disconnected.

Finally yet importantly, the Investigation Report seems to have won some popularity with netizens by identifying the disaster as both natural and man-made. According to *Global Times*, *Huanqiu shibao* in Chinese, a daily newspaper affiliated with the Chinese Communist Party's flagship newspaper, the *People's Daily*, “the unprecedented report, full of details, won unanimous applause from netizens for the depth and transparency of the investigation, with some saying they were moved into tears for the candid and responsible attitude and respect for human lives shown in the report toward reflecting on the tragedy.”[38] Given *Global Times*’ record of providing commentary on domestic and global affairs from nationalistic perspective, the report might be exaggerating and biased. However, investigation results shared by the Investigation Report with the public do help to restore the fuller picture of the floods in Henan, and of the rainfall in Zhengzhou in particular. Further, the Investigation Report’s self-critical stance should be seen as an effort to clear up deficiencies in emergency management as well as to learn lessons for the sake of future disaster management. Therefore, whether or not it serves a political purpose in response to public anger against the Chinese government’s performance in disaster preparation and crisis management, the Investigation Report has a constructive influence in not only improving the Chinese government’s credibility, but also in potentially contributing to future disaster risk reduction.

4. Self-help, mutual-help, public help

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[36] The Report, pp. 6-11.
[37] The Investigation Report, p. 3.
[38] “Investigation report aimed at correcting mistakes behind Henan flood, praised for people-centered approach of CPC”, January 22, 2022, https://www.globaltimes.cn/page/202201/1246610.shtml, accessed on May 28, 2022.

At a press conference held September 16, 2020, the then-Prime Minister of Japan, Yoshihide Suga told his audience that self-help, mutual help, and public help and "kizuna" (bonds) are the vision of society he aspired to.[39] Concepts of self-help, mutual help, and public help have been introduced into Japanese lives at the beginning of 1990s. Not only had the concepts been incorporated into Japan's social security mechanism,[40] but they are more widely used in the context of Japan's disaster management. When these terms are applied to disaster management and recovery, self-help means protecting one's own safety and that of one's family members, mutual help means protecting and supporting one's neighbors, and public help refers to assistance provided by public services, such as fire departments, the police, or (in the case of Japan) the Self-Defense Forces. The White Paper on Disaster Management of 2014 reports that in the Great Hanshin-Awaji Earthquake of January 1995, in which 6,400 people died, about 80% of survivors were rescued due to self-help and mutual help, while only 20% were rescued by the fire department, police, and Self-Defense Forces.[41] Further, the White Paper on Disaster Management of 2018 states that the percentage of people believing that "disaster management effort should be put into public help" decreased from 24.9% to 6.2% between 2002 and 2017 while those believing "disaster management effort should be put into mutual help" and "disaster management effort should be put into self-help" increased from 14% to 24.5%, and 18.6% to 39.8%, respectively, during the same period.[42] These survey results illustrate that in recent years the Japanese attach greater weight to self-help and mutual help than to public help.

When disaster in the form of rainfall and floods struck cities in Henan, the Chinese government, both at the provincial and the central level, sent government forces to rescue people in imminent danger as well as to strengthen the breached dykes and dams. On July 20, more than three hundred soldiers and officers from PLA Information Engineering University joined the rescue activities with emergency flood control equipment. The Chinese People's Armed Police Force, a paramilitary organization primarily responsible for internal security, was also added to the rescue force when the situation became worse.[43] But while public help played a leading role in disaster response, "the role of private rescue force should not be underestimated".[44] The private rescue force includes self-help, as in the case of those affected by the disaster actively posting their situation on SNS for help while waiting for public help, and mutual help provided by private rescue teams living nearby and able to reach those affected on short notice. For instance, in Mihe county, one of the hardest-hit towns in the Henan floods, 19 of the 23 bridges in the town collapsed, with only one road left for bicycles to travel between Mihe and the outside areas after the rainstorm on July 20th. Not only was transportation between villages cut off, but water and electricity were disrupted, too. Villages

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[39] Press Conference by the Prime Minister, September 16, 2020, https://japan.kantei.go.jp/99_suga/statement/202009/_00001.html, accessed on May 31, 2022.

[40] Annual Report on Health and Welfare of 2006 by the Ministry Health, Labour and Welfare of Japan, p. 172, https://www.mhlw.go.jp/wp/hakusyo/kousei/06/dl/1-3a.pdf, accessed on May 31, 2022.

[41] White Paper on Disaster Management, 2014, by Cabinet Office, p. 4, https://www.bousai.go.jp/kaigirep/hakusho/pdf/H26_gaiyou.pdf, accessed on May 31, 2022.

[42] White Paper on Disaster Management, 2018 by Cabinet Office, https://www.bousai.go.jp/kaigirep/hakusho/pdf/H30_fuzokusiryo2.pdf, accessed on June 2, 2022.

[43] "The People's Liberation Army and the Armed Police Force have carried out rescue and disaster relief in many places in Henan against the floods, July 21, 2021, http://www.xinhuanet.com/2021-07/21/c_1127678728_2.htm, accessed on June 2nd, 2022.

[44] Cover story "Rare rainfall in northern cities", *Sanlian Lifeweek Magazine*, Vol.31, 2021.

in Mihe suddenly became "isolated islands". Some villagers used SNS to call for help. Rescue teams seeing their messages identified their locations and reached the stranded people on the next day.[45]

It might be true that information provided by the government is used and valued more than information shared via social media, and that, moreover, in the case of natural and climate change-related disasters, where immediate action is required, social media is deemed less vital and trustworthy compared to official information.[46] However, social media platforms become more and more convenient and essential in people's self- and mutual help activities in which public help is unavailable or unreliable. The case of Mihe county shows that SNS, which is closest to disaster sites and victims in terms of time and space, can play an important role in self-empowerment in the future. Therefore, for any government, whether central or local, it is no longer wise to shoulder the problem on their own. Advantages of enterprises in capital and technology must be made use of to strengthen both self- and mutual help. Equally, the power of SNS should be appropriately employed.

Local governments carry the primary responsibility in the Chinese framework of disaster management. This includes not only the embedding of disaster reduction measures into their social and economic development plans but also the setting up of corresponding coordination offices to handle disaster reduction and relief work. Heads of local government are supposed to serve as chief commanders to organize field emergency response work, and report disaster details and progress to governments of higher levels.[47] This kind of institutional framework, in which local governments are supplemented by the central government, have been mainstreamed in disaster management for a long period in China. While the traditional "closed" operational mechanism, including decision-making and information sharing, might have been effective in lesser-scale rural disasters, urban disasters[48] in which public capacity is overwhelmed and unable to respond have increased in recent years.

When one talks about lessons learned and to be learned from a disaster, we are inclined to concentrate on lessons learned by the government, as if it were the government's sole responsibility to take care of its citizens' lives and property, especially in a country like China, where disaster management is implemented in a top-down manner. But while the Henan floods and many other disasters have demonstrated repeatedly that government-organized rescue forces might have the most advanced and professional rescue equipment, public help is no panacea in disaster response. Sometimes the government itself might be impaired by the disaster and unable to function properly. Sometimes the government lacks experience and has no established best practice to follow. Therefore, citizens must increase their awareness of the importance of self- and mutual help. In a training document publicized by FEMA (The Federal Emergency Management Agency), the roles of citizens and disaster victims include 1) assisting others;

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[45] Cover story "Rare rainfall in northern cities", Sanlian Lifeweek Magazine, Vol.31, 2021.

[46] Ingrid Boas and Chunci Chen "The role of social media-led and governmental information in China's urban disaster risk response: The case of Xiamen", *International Journal of Disaster Risk Reduction*, Vol. 51, December 2020, 101905, p. 9.

[47] Responsibilities of local governments that are required by the central government were In August 2007, the Chinese government issued the 11th Five-year Plan on Comprehensive Disaster Reduction https://reliefweb.int/report/china/full-text-chinas-actions-disaster-prevention-and-reduction

[48] Modern urban disasters here include both disasters occurred in urban cities and those occurred due to urbanization.

2) participating in a community or neighborhood-level disaster preparedness group; 3) volunteering with disaster relief organizations; 4) providing information to other victims or response and recovery agencies; 5) investigating disaster assistance eligibility; 6) applying for disaster recovery assistance.[49] Although it falls into the governments' duty to provide citizens disaster information and resources to build back, citizens, especially disaster victims, are core stakeholders in disaster participation who should not be excluded from disaster management framework. More and more research indicate that "the disaster management paradigm has shifted from being centralized and government-based to being decentralized, citizen-based, and participatory. The extensive participation of citizens during the occurrence of disasters not only provides support to relieve the gap of disaster damage and solve vulnerability but also has a positive influence on rebuilding after disasters as well as developing the local community."[50] The advantages of increasing citizens' participation in disaster reduction, management and recovery can be summarized as follows: 1) the more citizens are willing to participate in disaster management, the more confident they are in coping with emergencies; 2) the more actively they use social network tools to call for help, the better their chances of being rescued; 3) the more cooperative and pro-active victims of a disaster are when the disaster occurs, the better they will be able to help each other. Within the framework of disaster management, the relationship between citizens and their governments should be reconsidered and reshaped. To conclude, it is high time for both governments and their citizens to realize the importance of citizens' participation in disaster preparedness, management, and recovery, and their participation in the disaster management and relief activities should be socially encouraged, economically promoted and politically supported.

5. Working with international community and climate change

As is pointed out by leading scientists, "climate change is making the wettest days wetter, heightening flood risks" and "intensifies heavy rain events".[51] On July 21, the day after the start of the historic Zhengzhou rainfalls, the UN Climate Changes Twitter account stated that "dramatic climate impacts continue around the world. Zhengzhou in China has seen the highest daily rainfall since weather records began, receiving the equivalent of 8 months of rain in a single day. #COP26".[52] The closing chapter of the Investigation Report explicitly mentions the possible connection between the extremity of the natural disaster and climate change, which indicates that China is aware of the global trends in dealing with climate risks. The report states that "some leading cadres have lost their vigilance against major floods and waterlogging disasters in the perennial drought environment in the north; they have insufficient understanding of the frequent and harmful nature of extreme meteorological disasters in the context of global warming, and have a serious lack of risk awareness and bottom-line thinking."[53] Although the connection between the disaster and climate change is mentioned only in passing, the fact that it is mentioned at all displays China's

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[49] https://training.fema.gov/emiweb/downloads/hdr/session%204%20powerpoint.pdf

[50] Kim, S., Kwon, S. A., Lee, J. E., Ahn, B.-C., Lee, J. H., An, C., … Wang, J. (2020). "Analyzing the Role of Resource Factors in Citizens' Intention to Pay for and Participate in Disaster Management". *Sustainability*, 12(8), 3377. doi:10.3390/su12083377, p.1.

[51] "POURING IT ON: How Climate Change Intensifies Heavy Rain Events", May 15, 2019, https://www.climatecentral.org/news/report-pouring-it-on-climate-change-intensifies-heavy-rain-events, accessed on May 29, 2022.

[52] Twitter by UN Climate Change on July 21, 2021, https://twitter.com/unfccc/status/1417766452443164675?lang=en, accessed on May 31, 2022.

[53] The Report, p.36.

interests in dealing with climate change issues.

At the Third UN World Conference on Disaster Risk Reduction held in March 2015, the Sendai Framework for Disaster Risk Reduction 2015-2030, which outlines the following seven targets, was adopted. The framework is to be implemented over seven years, from 2016 to 2022, providing one year for each of its seven objectives:

2016: To reduce disaster mortality by 2030

2017: To reduce the number of people affected by 2030

2018: To reduce economic losses by 2030

2019: To reduce disaster damage to critical infrastructure and disruption of basic services by 2030

2020: To increase the number of countries with disaster risk reduction strategies by 2020

2021: To enhance international cooperation with developing countries by 2030

2022: To increase the availability of and access to multi-hazard early warning systems more readily available by 2030.[54]

It may be noted that the way in which the Henan floods were prepared for and managed does not even meet the first two or three targets, to reduce mortality, the number of people affected, and the economic loss, let alone the remaining four. The Henan floods demonstrate that it was due to the governments' unpreparedness and inexperience that mortality and the number of people affected have increased instead of being reduced, which is acknowledged by the Chinese government itself through the Investigation Report. As a result, it will be a long journey for China to reach the seven global targets of the Sendai Framework. Moreover, to achieve the goals, international cooperation is necessary, as was proposed at the 2021 International Day for Disaster Risk Reduction: "Only together can we save the planet!"[55] In its concluding section, the Investigation Report asserts that "(China should) borrow experience from Japan, Germany and other countries, and start disaster prevention and safety education from elementary education."[56] This should be taken as a message that the Chinese government is willing to learn from other countries and work together with them.

[54] *Sendai Framework for Disaster Risk Reduction 2015-2030* by UN, https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf, accessed on May 29, 2022.

[55] The Concept Note for the 2021 International Day for Disaster Risk Reduction, https://www.undrr.org/publication/2021-international-day-disaster-risk-reduction-sendai-seven-targets-campaign, accessed on May 31, 2022.

[56] The Report, p. 44.

7. Drought in Central Asia and how to manage it in an integrated way

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Central Asia is a vast region stretching from the Caspian Sea in the west to China in the east, and from Russia in the north to Afghanistan and Iran in the south (Figure 1). Covering an area of more than 4 000 000 km^2, the region includes five countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and sometimes Afghanistan is included as well.

Figure 1. Map of Central Asia including Afghanistan.
https://commons.wikimedia.org/w/index.php?curid=22746270

Prospective strategic priorities of Central Asian countries development are based on natural and socio-economic characteristics of each country (see Table 1). There are common development tendencies that, in the context of the water sector, can be formulated as follows:

- Enhancement of market relations and support of innovation-based entrepreneurship;
- Improvement of agricultural productivity and increase of crop processing, revival of cooperation;

- Organization of clusters, achievement of food security;
- Development of hydropower and renewables;
- Widespread digitization;
- Regional security.

Table 1. Key indicators of the Central Asian countries and Afghanistan (2018)

Country	Country area, Mha	Irrigated area, thousand ha	Population, million	GDP, billion $	Water resources formed within the country, km^3	Total water withdrawal of the country, km^3
Kazakhstan	272,50	1345,71	18,40	170,50	56,50	18,73
Kyrgyzstan	19,99	1024,50	6,26	7,95	47,30	5,53
Tajikistan	14,23	760,00	9,13	7,52	64,00	12,31
Turkmenistan	48,81	1553,10	5,85	40,76	1,40	25,38
Uzbekistan	44,90	4302,60	33,26	50,50	12,40	51,64
Total in CA	**400,42**	**8985,91**	**72,89**	**277,23**	**181,60**	**113,59**
Afghanistan	65,24	378,37	8,2*	20,51	21,23*	3,50*

Note: The data on irrigated area, population, water formation and water withdrawal of Afghanistan are shown for Northern Afghanistan only (Amu Darya, Harirud and Murghab River basins).
*Source: “Water Resources Management in Afghanistan”, presentation by Nasim Nuri at the International Economic Forum in Astana (2018) (Nuri, 2018[1]).

Country	Energy production total, Billion kWh	Hydroenergy production, Billion kWh
Kazakhstan	107,10	10,40
Kyrgyzstan	15,60	13,47
Tajikistan	19,70	18,40
Turkmenistan	21,20	0,00
Uzbekistan	62,80	6,50
Total in CA	**226,40**	**48,77**
Afghanistan	0,98	0,83

Note: Afghanistan, though not being a part of Central Asia, is included in this Table because of its considerable impact on the Amu Darya basin, especially in the future.

Source: The data on population and GDP (excluding Turkmenistan) are derived from national statistics (www.stat.gov.kz , www.stat.kg, www.stat.tj , https://stat.uz). Those data on Turkmenistan are taken from the World Bank's database (https://data.worldbank.org).

Central Asia: A region prone to drought

The climate of Central Asia is characterized by its landlocked position within the Eurasian continent. In winter, humid air masses from the Atlantic in the West and the Arctic zone in the North flow towards Central Asia. On their way across the continent, the air masses lose most of their moisture. Due to the cooling effect of the land masses, particularly in the mountain systems of the Tien Shan and Pamir, a zone of high-pressure forms -the quasi-stationary Asian maximum. This effect is strengthened in recent years due to the drying-up of the Aral Sea, since the water masses had a dampening effect. Due to this process, little precipitation falls during winters, which is mainly concentrated in the plains. In the mountain ranges, precipitation has decreased significantly. In combination with an increase in temperature, the glaciers in the region, a major source for water resources, are shrinking.

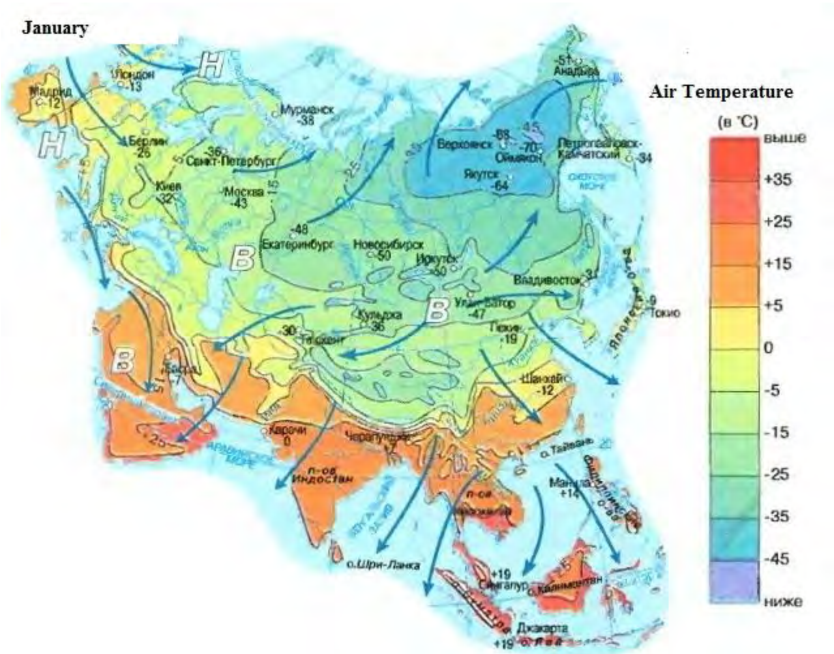

Figure 2. Winter season temperature regime and moisture transfer over the Eurasian continent
(source: http://worldofschool.ru/geografiya/stati/materiki/evraziya/klimat/obshhie-osobennosti-klimata-evrazii)

In summer, the meteorological conditions of Central Asia change fundamentally. Due to warming and a subsequent rising of the air masses over the land, the Asian maximum is replaced by an area of low pressure. The incoming air masses from southern and eastern oceans dry out and warm up on their way to Central Asia, leading to a very hot and dry climate with temperatures reaching over 30°C in July. Also, in the summer the disappearance of the Aral Sea has negative effects since the additional humidity from the lake is missing.

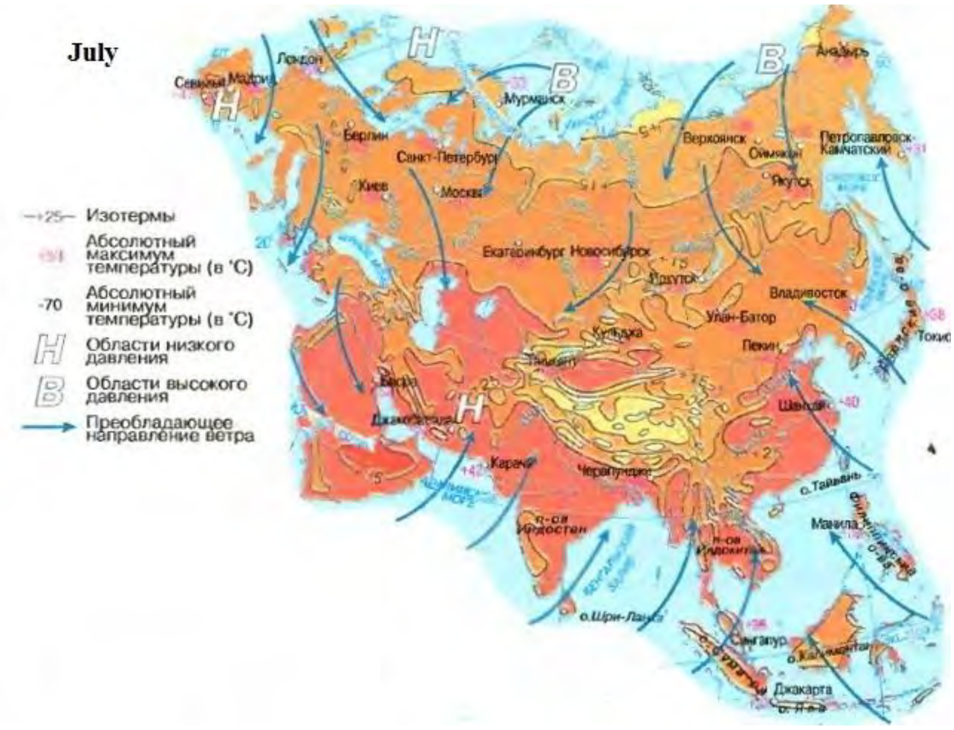

Figure 3. Summer season temperature regime and moisture transfer over the Eurasian continent.
The key is the same as in Figure 2.
(source: http://worldofschool.ru/geografiya/stati/materiki/evraziya/klimat/obshhie-osobennosti-klimata-evrazii)

Due to this dry climate, more than 2/3 of the territory of Central Asia is arid lands [2]. The effects of climate change in the region are projected to exacerbate the aridity. Temperature anomalies become more pronounced more frequent throughout all seasons in the region. Moreover, more days with heat waves are recorded in the Aral region (the so-called Prearalie) and in the lower reaches of the Amudarya River. River runoff did not undergo substantial transformations in this period of time. There is a certain downward tendency for small rivers' runoff, whereas in large river basins a decrease in runoff was minor (see Table 2). At the same time, the frequency and amplitude of extreme floods and water shortages have increased sharply.

The latest Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) from 2021 states that "aridity in East and West Central Asia is projected to increase, especially beyond the middle of the 21st century, and global warming levels beyond 2°C (medium confidence)" [3]. In addition to increased aridity, the glaciers are projected to decrease in volume by 30 to 100% by 2100. This means that currently more melting water is available due to the accelerated melting of the glaciers. But, the peak runoff is expected for the period between 2020 and 2040, at which point, the glacier runoff will decrease and in many areas disappear completely, along with the glaciers. In summary, climate change will increase temperatures and reduce precipitation for many areas of Central Asia, and the frequency and severity of droughts will increase as well.

In addition to climate change, the misuse of land during the Soviet era, including intensive irrigation, overgrazing of steppes, and clearing of mountain forests, caused numerous environmental impacts to the regional vast dry zone with limited environmental tolerance. Further economic growth has led to an increase in anthropogenic pressures and, as a result, land degradation.

It is estimated by FAO [5] that 4–10% of cultivated areas, 27–68% of pastures and 1–8% of forests are currently significantly degraded in Central Asia. The causes of land degradation are many, complex and vary from country to country, but they are generally linked to the overuse and overexploitation of the natural resource base, in particular poor and unsustainable agricultural practices, overgrazing of pastures, deforestation, forest degradation and natural disasters (the most famous crisis being that of the Aral Sea). The main forms of land degradation in the region include:

- Erosion, salinization and waterlogging;
- Degradation of pasture fertility;
- Decrease in fertility of arable dry lands and steppes;
- Reduction of areas and productivity of forests;
- Internal and external impacts of mining operations;
- Increased risk of landslides and flooding due to poor basin management;
- Decreased stability and functioning of desert, mountain, wetland and delta ecosystems.

Table 2. Assessment of river runoff in the Aral Sea Basin: changes occurred since 2000

Rivers in the Aral Sea basin	**SPECA**	**2000-2018**	**Change W1 - W**	
	W, km^3	**W1, km^3**	**km^3**	**%**
Syrdarya river Basin				
Naryn river – inflow to Toktogul HPS	14.54	13.70	- 0.84	- 5.8
Karadarya river – inflow to Andizhan reservoir	3.92	3.80	- 0.12	- 3.1
Chirchik river – inflow to Charvak reservoir	7.95	6.90	- 1.05	- 13.2
Total interstate rivers	26.41	24.40	- 2.01	- 7.6
Fergana Valley's rivers	7.81	8.2	0.39	5.0
Rivers of Chirchik, Akhangaran and Keles basin (excl. Chirchik), middle and lower reaches	2.98	3.7	0.72	24.0
Total in the Basin	37.2	36.3	- 0.9	- 2.4
Amudarya river Basin				
Vakhsh river – inflow to Nurek HPS	20.0	21.3	1.3	6.5
Panj river – Lower Panj section	34.29	33.5	- 0.79	- 2.3
Kunduz river – Askarkhana section	4.5	4.4	- 0.1	- 2.2
Kafirnigan river – accounted surface inflow	5.45	5.1	- 0.35	- 6.4
Surkhandarya – accounted surface inflow	3.32	3.3	- 0.02	- 0.6
Total for the Amudarya River	67.56	67.6	0.04	- 0.06
Kashkadarya river – accounted surface inflow	1.24	1.17	- 0.07	- 5.6

Rivers in the Aral Sea basin	SPECA	2000-2018	Change W1 - W	
	W, km^3	W1, km^3	km^3	%
Zarafshan – Dupuli bridge + Magiandarya – Sudji station	5.14	5.0	- 0.14	- 2.7
Rivers in Turkmenistan	3.1	2.9	- 0.2	- 6.5
Rivers in Northern Afghanistan	2.24	2.1	- 0.14	- 6.3
Total in the Basin	79.28	78.77	- 0.51	- 0.6
Total in the Aral Sea Basin	**116.48**	**115.07**	**- 1.41**	**- 1.2**

Unfortunately, ineffective policy implementation and weak institutional infrastructure, low technical, administrative and financial capacity of Central Asian countries, insufficient information exchange and imperfect hydrometeorological monitoring -all of these things contribute to an increase of vulnerability of the region to drought.

The latest drought in Central Asia started in April 2021 and affected all countries in the region, leading to a massive loss of livestock and crop failure in many areas. The effects of these kinds of droughts even continue when precipitation levels return to normal. In Karakalpakstan almost 500,000 hectares of irrigated land completely dried out, and the subsequent salinization will make it impossible to cultivate for several years to come.

The severe impacts of this drought revealed the high vulnerability of the region to drought. Not only the agricultural sector is affected, but also ecosystems and non-agricultural sectors of the economy were affected. The damage to agriculture was highest in rainfed areas, but irrigated areas also suffered. In many areas, there was not enough water left for irrigation, which even led to civil unrest in some countries [4].

Therefore, these droughts contribute to an increase in poverty as rural households lost major portions of their income when their crops failed or their livestock died. This in turn affects food security and public health through an increase in malnutrition and water-related diseases.

Regional cooperation: Towards integrated drought management

All countries of the region are now Parties to the United Nations Convention to Combat Desertification (UNCCD), and some of them are also members of other international environmental conventions and treaties. Over the years, activities within the UNCCD included the preparation of national action programmes (NAPs) to combat desertification, setting Land Degradation Neutrality (LDN) targets, development of the national drought policies in Tajikistan, Turkmenistan and Uzbekistan, and preparation of the Nationally Appropriate Mitigation Actions (NAMAs) in the context of sustainable development and climate change-related actions. The countries recognize the necessity for regional cooperation to encompass not only the NAPs, but other national action plans and national development priority documents to improve the socio-economic and ecological situations of the region.

While acknowledging government involvement in the support of agricultural producers, it should also be noted that not all countries are capable of or ready to provide both reactive and proactive countermeasures. Given that no country takes direct and indirect losses from droughts and water scarcity into account, promotion of proactive actions related to drought management and mitigation is quite complex.

Realizing that desertification and drought are transboundary problems that require joint action, and guided by the mechanisms laid down in the UNCCD, in September 2003 the countries of Central Asia adopted the Sub-regional Action Program to combat desertification in the context of the UNCCD[1]. In doing this, the countries could expect to benefit from further exchange of information and experiences, involvement of donors in the implementation of the UNCCD, synergies in the implementation of environmental conventions in the region, development and implementation of joint programs, and improvement of socio-economic conditions.

Later, this program served as a platform for launching the Central Asian Countries Initiative for Land Management (CACILM). Creation of CACILM can be considered as an interesting example of regional cooperation in the fight against desertification: cooperation took place between countries, between donors, and between countries and donor organizations. During the first phase (2006-2011) four regional and seven national pasture and agricultural land improvement projects were implemented. The main goal of the second phase (2018-2022) was to strengthen the integrated management of natural resources in drought-prone and saline agricultural production lands in the countries of Central Asia and Turkey.

Another example of regional cooperation is analytical project "Economics of Land Degradation in the Countries of Central Asia (2014-2016)", implemented with the aim of understanding and strengthening stakeholder awareness of the economic value of productive land, based on market and non-market values. The project was implemented under the auspices of the UNCCD with the participation of GIZ, ICARDA, the governments of countries of Central Asia and the Regional Environmental Center for Central Asia. According to the publication, the results of the project revealed that without action, costs to combat land degradation would amount to USD 53 Billion. That amount would increase to USD 288 Billion in losses over a 30-year horizon. Nevertheless, investments in restoration are cost-effective: There is a $5 return on every $1 spent on land restoration [6].

In addition, the UNCCD Secretariat initiated meetings to facilitate the exchange of information in Central Asia. For example, within the framework of the Central Asian International Environmental Forum held in Tashkent in June 2018, CAREC, in cooperation with the Secretariat, conducted a one-day training on reporting under the UNCCD. The main goal was to increase the capacity of the countries of Central Asia in fulfilling their obligations under the UNCCD, in particular, on reporting.

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[1] https://www.unccd.int/sites/default/files/relevant-links/2017-07/Sub-Regional%20Action%20Programmes%20%202.pdf

The suggested Way Forward: Joint Actions to manage drought from the Source to the Aral Sea

In order to avert the extreme effects of drought and the projected water scarcity under climate change and an increasing water demand in the region, quick and rigorous proactive measures are necessary, which can only be undertaken through regional collaboration and with the support of the international community.

Joint actions should be aimed at ensuring sufficient water resources to achieve the Sustainable Development Goals in the regional countries by 2030, as well as further socio-economic development, and achieve water, energy, food and environmental security for the countries and the region as a whole.

The integrity of the region's water resources has already been violated: the Aral Sea (a terminal and integral part of this system) has dried up, and the new Aralkum desert in its place has a negative impact on the stability of the entire water system. All previous efforts made in the region to stabilize the Aral zone so far did not show any effect. In addition, the glaciers shrinking and will be no longer feed the region's water resources in the future, as they are currently used.

Thus, a main goal of joint actions should be to find solutions and implement them to manage the ecosystems in a sustainable way so they can contribute to reducing the impacts of climate change. Innovative approaches are needed to sustain ecosystems in the upper watersheds in order to increase the volume of water resources and reverse the diminishment of the Aral Sea, so as to support further socio-economic development in the region.

It can be positively noted that initial actions have already been launched in the region. However, it is necessary to scale them up and strengthen them, by attracting more funding and implementing them within the framework of a coordinated regional program. These initial efforts include the Aral Sea Basin Programme (ASBP-4) (https://ecifas-tj.org/en/meropriyatiya/aral-sea-basin-program-4-asbp-4/), where countries have identified and agreed on priority projects for the region. These projects include the development of a regional action plan for adaptation to climate change to make the sectors most vulnerable to water scarcity, like agriculture and energy, more resilient against climate change impacts, but also to sustain biodiversity and the ecosystems in the region. The programme intends to introduce advanced methods to update the irrigation regime for crops, as well as introduce water saving and water reuse technologies in all water use sectors. Other projects within the ASBP-4 address drought directly, but also consider other water disasters like floods and mudslides or efforts to better understand the glacier melt processes in the region as a basis for better long-term planning for water resources.

The Regional Strategy for Drought Management and Mitigation in Central Asia for 2021-2030, is another fundamental pillar to reduce vulnerability to droughts in the region. Developed in 2021 by experts from all Central Asian countries, the project was funded by the UNCCD and implemented by the Regional Environmental Center for Central Asia (CAREC).

The strategy proposes four regionally identified priority areas for managing drought risk based on the three pillars of integrated drought management, promoted by the integrated Drought management Programme (IDMP, https://www.droughtmanagement.info/), to be carried out through a whole-of-society approach (national and regional):

Priority Area 1: Building capacity for monitoring, risk assessment and drought prevention

Priority Area 2: Drought mitigation, development of plans to address water scarcity and dissemination of data

Priority Area 3: Capacity Building and Awareness Raising

Priority Area 4: Regional cooperation to implement the strategy's action plan

The strategy provides an overall framework, but joint efforts are necessary for its implementation from local to national and regional levels. International partners like FAO, GWP, WMO, as well as national partners are ready to support the countries in the region. A prime example is a project of the Japanese government on the "Development of innovative climate-resilient technologies for monitoring and controlling the efficiency of water use and the impact of salinity on crop productivity and living standards in the Aral Sea region" under the "Partnership in Scientific and Technological Research for Sustainable Development" (SATREPS) program.

Agriculture still represents the largest water demand of all sectors in the region. Therefore, the promotion of water-saving technologies and increased productivity and efficiency of water use for irrigation remain key. Specific recommendations for future efforts in this regard include:

- Further development of governmental support systems for agricultural producers using water-saving methods and technologies;
- Widespread introduction of water-saving technologies in irrigated areas that are using pumping stations and pumping units, including areas irrigated from wells and vertical drainage wells;
- Improving mechanisms to stimulate research addressing water saving methods and technologies, taking into account a variety of soil, climate and other regional characteristics in the country and taking into account lessons of previous pilots, including the development of highly efficient systems that require lower maintenance costs;
- Improving mutual cooperation between industrial sectors for production of components and spare parts for water-saving irrigation systems, including drip and sprinkler irrigation technologies;
- Raising awareness for water conservation technologies, including highly efficient surface irrigation methods;
- Development of guidelines for design, implementation and application of water-saving technologies, as well as criteria for evaluating their effectiveness based on the specifics of irrigated areas, crops and varieties;
- Organization of training, retraining and advanced training for specialists in the implementation and use of water-saving irrigation practices and technologies;

- Expansion of technologies for development of sowing schemes using automatic laser planners, as well as an underground closed irrigation system using modern flexible pipes;
- Development and implementation of science-based water circulation standards in industry and public utilities;
- Use of remote sensing systems for monitoring and targeted improvement of water productivity;
- Implementation of water rotation and other measures, as well as technologies to control water losses at field level and non-revenue water.

Currently, the International Fund for saving the Aral Sea (IFAS) and its structures have an interstate mandate to strengthen a region-wide inter-sectoral dialogue on environmental protection and sustainable development, as well as rational use of water resources. The region, therefore, has the institutional capacity to build a dialogue and establish a framework for drought risk management and mitigation. IFAS is looking for support and cooperation in those directions with international partners.

References

1. Nuri, N. (2018), *Water Resources Management in Afghanistan*, International Economic Forum in Astana.
2. World Bank, Climate Change Knowledge Portal (https://climateknowledgeportal.worldbank.org)
3. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.
4. Ryskeldi Satke (2021) : Central Asian Drought Highlights Water Vulnerability, https://www.preventionweb.net/news/central-asian-drought-highlights-water-vulnerability
5. Drought Characteristics and Management in Central Asia and Turkey. FAO Water report 44, Rome, 2017, 114 p.
6. Emmanuelle Quillerou, Richard Thomas, Oleg Guchgeldiyeg, Stefanie Ettling, Hannes Etter, Naomi Stewart. Broadening Land Management Options for Improved Economic Sustainability across Central Asia: A synthesis of National Studies. ICARDA, 2016

8. The 2021 European flash floods – learning through economic, ecological and social perspectives

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From July 12-July 19 2021, low-pressure system "Bernd" brought heavy rainfall to Western Europe leading to severe flooding in several Western German states, particularly along the rivers Erft and Ahr, 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. Across the continent, over 230 people died in the floods. Germany suffered the highest death toll with 186 casualties (134 in the Ahr valley alone), followed by Belgium with 42 casualties. Preliminary estimates of the total economic losses in the affected areas across Europe range from 45 to 55 bn USD and are estimated to be between 35-40 bn USD for Germany alone. This makes the 2021 floods the costliest disaster in Germany and the deadliest in roughly sixty years. Also 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 10-13 bn USD range across Europe and ca. 9.7 bn USD for Germany. In comparison, this is the costliest recorded disaster from a natural hazard for Germany, above the losses from the two major river floods (2002, 2013) and storm "Kyrill" (2007).

The high human and economic costs of the event brought systemic problems of flood risk management system to light – some of which not new. Our initial analysis focuses on the failure of achieving tangible actions from the early warning systems, the challenge of incorporating historic events into the data record to delineate flood zones, the breakdown of critical lifeline infrastructure - in particular related to telecommunication and road access - and coordination challenges in the response phase. A deeper understanding of resilience and holistic disaster risk management (DRM) is missing, and a shift of awareness and the ability to appropriately act is necessary in light of more intense and frequent weather systems 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 floods, the severity of which have been linked to climate change, came at a time where 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 fight 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. If 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 these look like? And how do we ensure that this flood event helps us learn lessons not just for those areas that were affected this time, but in particular areas with similarities to the Ahr valley and others that could suffer similar losses in a future flood.

This chapter details our Zurich Flood Resilience Alliance - Post Event Review Capability (PERC) study of these floods and provides **preliminary** findings, looking through the elements of the DRM lens and focusing on socio-economic and nature-based elements. The full PERC report will be published later in 2022[1].

(1) Our approach to review the 2021 European summer flash floods

Developed as part of Zurich Insurance Company's flood "Zurich Flood Resilience Alliance"[2], the Post Event Review Capability (PERC) provides a methodology for undertaking forensic analysis and independent reviews of large disaster events, while providing accessible, consistent, and generalizable insights. There is a need to build and enhance resilience people and organizations, services, infrastructure and livelihood systems if risk is to be proactively reduced, given the global growth of hazard, exposure and vulnerability[i],[ii]. The 2015–2030 Sendai Framework for Disaster Risk Reduction identifies the urgent need for learning about disasters. Yet, unfortunately, it is well established that this is not easily achieved[iii]. A forensic disaster analysis methodology like PERC helps to capture new insights and review lessons of the past, both within and across disciplinary boundaries, especially in the dynamic contexts of urbanization and climate change. Its focus on lessons and recommendations relevant for building disaster resilience distinguishes it from disaster impact assessment approaches such as Damage and Loss Assessments (DaLA) and Post Disaster Needs Assessments (PDNA). PERC is open source and our second, updated manual on its use has been published[iv].

PERC seeks to answer questions related to disaster resilience, DRM, and catastrophe intervention. It looks at what worked well (identifying best practice) and opportunities for improvements (providing actionable recommendations). It highlights that, while hazards are natural, disasters are not; there is a choice to act early to prevent the creation of new risk and reduce existing risk, and that the choice very often is not only the right one from a humanitarian perspective but is also cost-effective. Building disaster resilience goes beyond engineering grey infrastructure-type solutions to fight hazards such as flood waters, to incorporating social and ecological approaches as well.

(2) Overview of the disaster

From July 12-July 19 2021, low-pressure system "Bernd" brought heavy rainfall to Western Europe leading to severe flooding in several German states, in particular North Rhine-Westphalia (NRW) and Rhineland Palatinate (RLP), particularly along the rivers Erft and Ahr, and in Belgium and the Netherlands along the Meuse river and its tributaries and in Luxemburg along the Sauer. Further affected were Eastern parts of Germany (Saxony and Bavaria), Austria, Italy and Switzerland amongst others.

Early indications of potential severe weather became evident a few days ahead of the event materializing. The European Flood Awareness System (EFAS), established as an early warning mechanism for extreme situations for participating members in the Emergency Management Service, highlighted a high probability of flooding for the Rhine on July 9 and 10, 2022 and also for the Meuse then on July 11[3]. However, at this point, uncertainty which exact

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[1] https://floodresilience.net/perc/

[2] https://www.zurich.com/flood-resilience

[3] https://www.efas.eu/en/news/faq-efas-and-recent-flood-events

areas would be affected remained high given the nature of the meteorological situation. Particularly, for a small country like Luxemburg it was not clear whether they would be affected at all. This uncertainty prevented taken action earlier. Between July 11 and 12, it became clearer to national weather services that "Bernd" would be moving to the Western and Central part of continental Europe and potentially bring damaging amounts of rainfall. This situation was exacerbated by antecedent conditions and by the topography of certain areas. There were saturated soils from earlier precipitation already, with locally less than 10 mm of further absorptive capacity remaining (DWD). The affected regions comprise small valley sections with very narrow and steep slopes of old rivers, causing funnel-like effects. The Ahr river valley in particular is deeply incised into the Rhine Slate mountains ("Rheinisches Schiefergebirge") and prone to flooding in what is topographically more similar to a gorge than a valley in some places – it was also called a "flashy region" or rapid reaction catchments by hydrologists, outlining the speed with which these areas generates runoff, leading to a steep and peaky flood wave, and consequently to very short reaction times.

In Germany, a first series of thunderstorms with intense precipitation moved through NRW in the night of 13-14 July. The main rainfall event with very elevated precipitation levels causing to the floods along the mentioned rivers moved through BENELUX and Germany on 14 July. The ex-post analysis of the German Weather Service (DWD) indicated rainfall totals of 150 mm in distinct areas and widespread rainfall of over 125 mm for a duration of 72 hours. Peak measurements were 241 mm in only 22 hours at weather station Hagen in NRW in the Ruhr catchment, on July 13. From 14-15 July, rainfall was persistent, leading to another 150 mm areas across the region. To qualify these numbers, an "unusually high number of stations" of ca. 30 measurement stations recorded new highs (DWD) with estimated (local) return periods less frequent than 1 in 100 years. However, no new all-time records were measured for Germany in this event.

The rainfall led to devastating flooding. In Germany, a particularly affected area was 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 river, where the damaged Steinbach dam is located. Later that week as the rainfall subsided, more problems occurred in areas along the Rur, where the Rur valley dam overflowed and where a levee near Ophoven broke, leading to widespread flooding in downstream communities.

River gauge data is quite scarce for these smaller and mid-size rivers compared to the Rhine and Elbe river due to their characteristics, and if available rather downstream, serving the flood predictions for the main rivers but unsuitable to provide forecasts for the communities along those rivers, but also because those river gauges that were available were destroyed or measured unreliably during the event. In Altenahr, the prior measurement record at the gauge station[4] was 3.71 m. Water levels reached 6m on Thursday 15 July as the gauge stopped working. Latest estimates from authorities assumed that water levels were 7m or more in the gauge area, and field observations and

[4] https://www.hochwasser-rlp.de/karte/einzelpegel/flussgebiet/rhein/teilgebiet/mittelrhein/pegel/ALTENAHR

calibrations estimate the level to be as high as 10m. Experts in historic hydrology have calculated that the order of magnitude for the peak flow was between 1000 and 1200 m3/s, comparable with the biggest historic event in 1804. Another devastating flood also occurred in 1910.

While the World Weather Attribution report estimates the July 2021 Ahr river flood to be a >500 year RP event based on preliminary data[v],[vi]., several devastating floods in the Ahr region are known to have occurred in the last few centuries. Big floods with great devastation and many deaths took place in the summers of 1804 and 1910 and are well documented including a series of photographs taken during and after the floods rushed through the valley but have not been measured using "modern" flood measurements, i.e. no gauge data exists. In 2021, peak water levels in Dernau at the Ahr are assumed to be 1.5 m higher than in the 1804 flood.

There are questions about the reason for these increased water depths especially as it can be assumed, based on latest reconstructions, that the water flow in 2021 was similar to the 1804 flood. Elements that are discussed to have contributed to the height of the flood are the natural state of the valley incl. a lot of organic flood-borne debris (tree trunks etc.), human-made debris (cars and caravans from camping sites along the river, etc.), a narrower riverbed that can transport the water, increased settlement areas, low bridges, and seasonal effects (state of the plant growth) all leading to increased roughness and reduced ability for water to flow off are being discussed by experts as contributing elements to the height of the flood.

We analyzed the available time series of river gauge data and note that the 100-year flow level (HQ100) is interpolated from reliable measurements that date back in some cases fewer than 50 years (the measurement record at Altenahr in the Ahr valley dates back to 1946). This interpolation of gauge data is not making use of all available information incl. historic data and leads to a certain blindness of what an HQ100 flow actually could be – the 2021 flood certainly is not an event that was beyond imagination and probably not even beyond what was experienced in the past. Only relying on the measured record does not capture well less-frequent, more extreme events, and shows the necessity to incorporate other indications (such as paleo-events or historic written and oral records without detailed flood measurements) into an analysis for the determination of flood hazard maps and for flood zoning. While this is not common practice, we were told that guidance and manuals for the determination of HQ100 would already allow the incorporation of such information. Beyond the known events, both flood hazard mapping for land use and building codes as well as rapid flood mapping for emergency purposes should consider outlining the maximum probable flood extent. This is especially true under the impression of future climate change and an enhanced shift of flood regimes, where just relying on past information (assuming a stationarity in the system that is no longer true) will be misleading.

For Luxembourg and the Netherlands, flood conditions are more regularly expected in winter. However, this type of more frequent and intense summer flooding that occurred in July 2021 may constitute a regime shift. The stationarity of "Bernd" over Central Europe affected Luxembourg with over 12 hours of continuous rainfall. Two of their weather stations recorded new maxima for 24 hours (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 100 year flood level was exceeded, with absolute records measured at 15 stations – and again noteworthy that prior records were set in winter, but “Bernd” led to a summer flood.

In the Netherlands, the large ensemble of model simulations indicates the probability of the observed Meuse two-day rainfall and peak discharge is on the order of 1:100 to 1:1000 per year. 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. 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.

In Belgium, the storm stalled between 13 and 16 July, leading to maximum precipitation of 291mm in 72 hours measured in Jalhay, 230mm in Spa, 213mm in Mont-Rigi, and 209mm in Ternell. Most of this rainfall occurred on 14 and 15 July. Depending on the method, the estimated return periods for this amount of rainfall range between 100 and 1000 years. However, only limited time series data from the above weather stations is available with Jalhay having the longest time series but still only reaching back to 1986. Uncertainty for the estimated return periods is thus high. Reports note that the spatial extent of the event is very large for an event of such rain intensity, which usually corresponds to more localized, short and stormy events.

Between July 13 and 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 43.4m^3/s on 14 July. The Pepinster sur l'Hoëgne station also has recorded part of the flood, with a maximum flow of 390m^3/s on 14 July. 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 400m^3/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 575m^3/s. Similarly, estimates based on water marks further downstream show values of 535m^3/s in Trooz and 600m^3/s in Chaudfontaine. For the river Ourthe, the maximum discharge at Sauheid was around 1150m^3/s and at Angleur around 1429m^3/s. For the river Amblève, the discharge at Martinrive 661 was m^3/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 return period of 200 years was estimated. For downstream parts this could even be higher. For the Ourthe and Amblève the estimated return periods are 25 to 50 years in the upstream parts and up to 100 years in the downstream parts.

Overall, it is noteworthy that the 2021 floods have resulted in morphological changes in many rivers which need to be assessed to understand how flood hazard for the future is changed. Also given the severity of the flooding and the unusual flood extent, flood hazard maps are being revised and updated to incorporate the latest experiences, which is ongoing work in progress – some have already started revising the flood maps (e.g. along the Ahr), in other locations there is awareness that this is a key task that needs to be tackled (e.g. along the Rur tributaries), and this should also serve as a call for others to follow suit. It is important that these upgrades are not only made in the most affected areas, but that learnings are incorporated in flood maps throughout, even where there was no damage this time.

The World Weather Attribution (WWA) project assesses that weather patterns that led to the severe flooding in Western Europe are made more likely by climate change, but an individual attribution to the event is not possible because it was too localized. Instead they looked at such weather patterns for Western Europe and conclude that for any single given location within the larger region an event of this size would be expected once every 400 years (but more frequently across Western Europe overall). Compared to a pre-industrial global climate (-1.2C), the WWA finds that the maximum 1-day rainfall amount for summer in this region has increased by 3-19%, making the occurrence of a similar event 1.2-9 times more likely today. In a 2°C warmer climate over preindustrial it would be further more likely by a factor of 1.2-1.4. The WWA report was mostly looking at rainfall as the parameter, since the hydrological data is too unclear to be used, mostly because many measurements were imprecise or unavailable at the peak flood due to the gauges being destroyed.
More details on the physical assessment of low-pressure system Bernd and the subsequent flooding, especially for Germany, are found in other chapters in this UN HELP report (Kron et al., "The July 2021 flood disaster in Germany").

Initial findings from an analysis of the physical event point towards the need to incorporate the 2021 summer floods into flood scenarios to inform future actions that can build societies' resilience. Evidence suggests that the rainfall event caused by "Bernd" will occur more frequently than it has been in the past as a result of climate change. Therefore, it is unwise to treat events like "Bernd" as an extremely unlikely outlier. Rather, there is a need to incorporate such storms into our field of vision to both be aware of and better prepared for similar and more extreme events. In addition, flood events of the magnitude of 2021 in the Ahr valley have occurred in the historic past and are therefore not something like "never seen before".

(3) Economic and insured losses

Preliminary estimates of the total economic losses in the affected areas across Europe range from 45 to 55 bn USD and are estimated to be between 35-40 bn USD for Germany alone. Early estimates indicate that Rhineland-Palatinate accounts for over half of the losses for Germany, with roughly 20 bn EUR total economic and 5 bn EUR insured losses. This makes the 2021 floods the costliest disaster in Germany and the deadliest in ca. sixty years. Similarly for the insurance industry, this event was reported as the largest industry loss for 2021, with estimates of insured losses by the market in the 10-13 bn USD range across Europe and ca. 9.7 bn USD for Germany. The German Insurance Association (GDV) originally estimated that for their country coverage, the insured loss would be approx. 5.7 billion EUR but increased this later to 8.2 billion EUR as the extent of claims became clearer. The losses are spread across around 250'000 claims made (up from an earlier estimate of 190'000), most of which are located in North Rhine-

Westphalia and Rhineland-Palatinate. The state directorate of Rhineland-Palatine estimates the losses in their state to be up to 20 bn EUR, of which ¾ are uninsured. Of the insured losses, they are split between property (7.7 bn EUR) and motor (0.45 bn EUR) insurance. In the Ahr valley, 42'000 people were affected by the floods in Ahrweiler district, and approx. 8800 buildings were destroyed or had to or will have to be condemned. Furthermore, 103 bridges in the Ahr valley were destroyed or significantly damaged by the flood so they are beyond repair and will need to be condemned. In the Netherlands, most of the damage occurred in the tributaries of the Meuse river around the city of. Valkenburg, with total losses expected in the 350-600 mn EUR range. Of these losses, most are to public infrastructure and only about 5% are attributed to private property.

In comparison, this is the costliest disaster from a natural hazard for Germany, above the losses from the two major river floods in 2002 and 2013 (which JBA Risk Management had estimated at 13 bn USD and 16.5 bn USD total economic losses, respectively) and also costlier than storm "Kyrill" of 2007. All of these had a much larger footprint than the extent of the flooding from "Bernd", which illustrates its severity.

There is a remarkable trend of early loss estimates being on the low end, later updated with higher figures as more data became available. There are mainly three reasons for this increase in loss estimates:

(1) The flood extent. Depending on whether the flood models are derived based on flood gauge data or use an integrated rainfall-to-runoff approach, the models tended to underestimate the flood extent. Later information, making use of satellite data and actual observations of flood levels in the field, increased the flood extent closer to its actual size, incorporating more assets into the footprint, evidenced by the increase in the number of claims. This underestimation of the flood extent is in line with the earlier discussion about the procedures to estimate HQ100 and both a move to incorporate forward-looking and probabilistic scenarios as well as the inclusion of more historic data to cover a wider spectrum of actual events is required.

(2) The severity of the flood. There seemed to be insufficient experience with this type of flood in smaller and smallest watersheds as opposed to larger rivers, where there is better experience of understanding damage extents based on gauge data or flood depths. These were floods with high water velocity and a high extent of flood-borne debris, increasing the fractional damage as well as the amount of total losses of buildings, including due to contamination that rendered repairs impossible (e.g. oil spills). As the regime of flooding seems to be shifting both seasonally as well as geographically, a swift increase in the experience in dealing with these effects is necessary.

(3) Increased cost. Claims cost were significantly higher following this event for the following reasons:

(a) Due to a construction surge and increased cost of material already persistent before the event;

(b) due to supply chain and delivery problems also in part due to the COVID-19 pandemic and global effects; and

(c) due to additional increase costs of working following the flood event itself, part of which is typical and observed often during such large-scale catastrophe events, but partially also unsubstantiated and for which insurance companies have supported affected customers to ensure unfair price demands were challenged.

In response to the devastating losses and damages to private households, businesses, agriculture and infrastructure caused by the floods following storm “Bernd”, the countries with the most affected regions, Germany, Belgium, the Netherlands and Luxemburg, have released emergency and recovery funds to cover the uninsured losses and provide immediate financial support for those most in need.

As the most affected country by storm “Bernd”, the German parliament has agreed on a recovery fund (Aufbauhilfe 2021) with a total volume of EUR 30 bn. Of the EUR 30 bn, EUR 2 bn are used directly by the federal government to repair and reconstruct national infrastructure, while the rest is distributed between the most affected federal states, NRW and RLP. They can use up to EUR 15.2 bn and EUR 12.3 bn from the fund, respectively. Smaller amounts (>=1%) of the fund can be accessed by the states of Bavaria and Saxony who have not been severely affected.

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 mn for emergency relief and has so far paid out EUR 102.4 mn to private households, EUR 35.7 mn to businesses and industry and EUR 65 mn to local authorities. RLP has paid out EUR 35.3 mn to private households, EUR 13.1 mn to businesses and industry and EUR 118.9 mn 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 Belgium, the losses from the flood events following storm “Bernd” including emergency relief were handled by insurers. However, the governments of Belgium have previously negotiated a maximum cap for insurers of EUR 320 mn, with anything above covered by the Belgium disaster relief fund. In response to the flood event the government of Wallonia negotiated with the insurance industry to increase the cap to EUR 590 mn, which still only covers around 29% of the total losses of EUR 2.16 bn paid out so far.

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 mn, which provided a direct emergency payment of EUR 2000 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 damages. Uninsured losses were covered by the state through the disaster compensation act (Wts), which have paid out of EUR 13.9 mn (as of March 2nd 2022).

The government of Luxemburg has provided EUR 50 mn in emergency relief funding directly after the event. It was paid out 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.

(4) Key findings from an analysis of the disaster risk management cycle

The high human and economic costs of the event brought systemic problems of flood risk management system to light – some of which had been known for a long time. For example, initial analyses and debates focused on the failure of the messaging chain in the early warning system and problems in the response phase. We argue, however, that even if warnings had better and more quickly reached the population, and even if the response phase had been more swiftly and better coordinated, that the consequences from the floods would still have been dire. To date, a deeper understanding of resilience, systems thinking and perspectives looking at the whole disaster risk management (DRM) cycle is missing, as is a societal memory of severe flood and other disaster events and how to use generational knowledge and memory to improve preparedness and appropriate action.

Overall, the death toll across the event stands roughly at 230, with the majority – ca. 186 – from Germany, 42 from Belgium, and individual deaths and missing people reported from other affected countries. In Germany, the most affected state was Rhineland-Palatinate with 135 deaths, and the most affected river was the Ahr, with 134 fatalities reported from the Ahr valley. 69 alone are from Ahrweiler, 33 from Altenahr and 13 from Sinzig. One statistic that stood out is the age disaggregation of the flood victims along the Ahr – 106 out of the 134 deaths were people over 60 years of age. This leaves the questions whether the particular preparedness needs that older and more vulnerable people are dealt with and whether additional protection needs for these groups can be better incorporated into flood risk management. Besides the significant infrastructure and critical lifeline failures, 7 hospitals and clinics, 19 nursing homes and other services critical for the elderly were affected during the floods.

Preparedness and Early Warning

From a weather observation point of view, there are indications that the weather system "Bernd" and its potentially damaging consequences were forecast quite well, both at the European level (The European Flood Awareness System EFAS had the situation on its radar and provided early yet somewhat vague notifications) as well as the national level. The German Weather Service DWD, which is also the institution legally required to provide weather warnings to public services and the population, also provided warnings as early as 12 July, and anticipatory actions such as the lowering of certain water levels in dammed lakes in the Wuppertal area for example, were taken.

Moving from rainfall to runoff, the picture of how flood warnings were derived and disseminated is more complex. There was a less clear understanding of how the precipitation from "Bernd" would unfold in the river systems, and coupled with the existing flood hazard maps outlining the HQ100 and HQextreme extent, for many it seemed unimaginable that the actual flood extent and flow velocity could be so much above what was in the official maps.

As the flooding became imminent, it remained unclear what the extent of the flooding would be. As mentioned many of the affected regions are "flashy" in nature and generate runoff quickly. An exact forecast of the flood levels was difficult, and actual gauge levels turned out to be higher than expected. Hydrologists at the GFZ Potsdam are exploring the application of a new type of rapid 2D-models that uses the gauge prediction as input to provide a real-time forecast of the extent of flooding. This would help with emergency planning and the amount of advisable evacuation – in the case of the Ahr valley, an evacuation of perimeter of 50 m from the river was ordered, but the extent of the actual flooding showed this was far below what would have been necessary. A flood extent model with swift calculation times, even with uncertainty, could be a big improvement over just having gauge data, which also has significant uncertainty. The move to using different modeling approaches to use the best real-time or near-real-time information to understand what's happening in a river system would be a first step. To arrive at legally binding flood hazard maps is a different step altogether and requires a societal discussion, similar to the discussion necessary of how historic data should be used alongside measurement data. At the national level, the relevant office is the Federal Office of Civil Protection and Disaster Assistance (BBK). As the name suggests, it has national authority in case of war, but only has a subsidiary function during peace time in case of disasters. In peace times, disaster preparedness and response is decentrally organized, with the German states in charge. The BBK is only providing additional services for information-gathering, -sharing and response coordination upon request by more than one state.

Response

To move from warning to action, a clear picture of the situation and an action plan to activate coordinated response mechanisms are required. In Germany, the alarm and response system are decentrally organized, using subsidiarity principles, with the aim to put those in charge who are closest to the situation and would know best what's needed. Content to feed warnings into the dissemination mechanism is input at regional or local level depending on each state's disaster law. As one of the services of the BBK, a joint information center ("Gemeinsames Melde- und Lagezentrum GMLZ) consolidates all the information received through the channels, but cannot take further action unless requested to do so. BBK also operates a central, modular warning system MoWaS, 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.

For the actual warnings and alarm messages to reach the population and end-users in regional and local public offices, a variety of pathways and a variety of means can be used within MoWaS. These range from classic media like TV and radio to phone communication and loudspeaker announcements on cars roaming the streets, to warning portals on the internet, paging services and city billboards, amongst others. Additionally, authorities used sirens where still available (the implementation of sirens into MoWaS is currently being attempted). A big focus recently was on internet-based digital applications such as weather warning Apps and the emergency information App "NINA" from BBK. Additionally, there are warning systems such as "KatWarn", which also features an App, operated by a private-public set of institutions[5]. The downside of all these Apps is that they are subscriber based – users need to actively download them to their devices. Another technology, not yet implemented in Germany but considered, are cell broadcast services, which distribute warning messages directly to any phone registered to a cell for which the warning is active.

It seems that challenges started here in the warning chain, not with the absence of warnings themselves but with the

[5] https://www.fokus.fraunhofer.de/go/katwarn

dissemination, reach and understanding of the messages, which contributed to the high number of fatalities. This is currently subject to wide-ranging political and legal investigations and it would be premature in this report to draw any conclusions. What's been reported so far through media and channels who know more about the ongoing investigations is that the situation rapidly became chaotic once the event started unfolding, but that the warning messages as such were there and disseminated, so people and key actors could have known. The following items are worth highlighting:

- There was limited understanding and clarity on which channels to use to disseminate the warnings and especially the urgency of the warnings, and while national stations received instructions, many regional and local ones seemingly did not or were not clear about the immediacy of the action needed.
- The nationally provided warning systems and Apps incl. NINA reportedly functioned as planned, i.e. all messages that were fed in from state and local level were disseminated – but the use of them are optional and other mechanisms could be used by local and regional authorities. Furthermore, while there was an agreement in place that all warning messages from the KatWarn service are fed to the NINA App and vice versa that public warnings from MoWaS would feed the App from KatWarn, this was not the case of the Ahr valley, where KatWarn was used, which is currently subject to investigations. A more stable system with clearer roles and responsibilities and less "optional" approaches are needed.
- Many channels including internet and mobile App failed with the widespread infrastructure failure. It is clear that a multi-channel approach dedicated at reaching the breadth of the population with their own behavioral choices is necessary. No single channel can achieve a thorough and widespread warning, yet, more clarity on how these channels are operated and what messages can be effectively transmitted to which user groups (professional versus lay end user) is required.
- Warnings were often too technical in nature and did not include specific actionable advice how to protect oneself but remained vague informing about gauge water levels and the equivalent warning stage this represented. Our initial analysis of the warnings issued by local authorities through the MoWaS revealed large differences between content in warning messages. Particularly noteworthy is that in the most affected area, the district of Ahrweiler, district-level control centers did not issue warnings in MoWaS. In other districts in both NRW and RLP, warnings were issued before, during and after the floods. Yet, even here, the message content, particularly regarding recommended actions, differed significantly between jurisdictions. In some cases detailed actionable advice was given, in others not. Notably, standardized codes for MoWaS which enable warnings in several languages were not always used. Thereby, in many cases critical information was only available in German.
- Warnings were not commented or explained, and initially seemed not to be different from weather warnings announcing storms in the week prior to the floods from "Bernd". As the potential severity of the event was not made clear, many people were surprised by the intensity and speed of the floods. One attempt to explain many of the fatalities – besides the demographics and the large skew toward the elderly 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. This seems to be a common challenge, and awareness-raising, training and clear communication about the dangers of these behaviors can limit loss of life.

- Warnings which included unusually high predictions of gauge levels were doubted or assessed as erroneous in some cases. People found them completely disproportionate compared to floods experience in the (recent) past. The extent by which this flood surpassed the mapped hazard played an important role and was already discussed earlier in this chapter. Moreover, collective "memory loss" of flood events contributed to the problem – people not being knowledgeable about how bad floods can be and that serious floods where they live did happen in the past. For example along the Ahr, the "available" flood memory made people compare the expected situation in 2021 to the 2016 flood. To address this, elsewhere, there have been successful communication and visibility campaigns to remember and visualize historic floods using flood markers along affected streets and houses, painting evacuation routes and flood extent limits so they are directly visible, and providing space for both mourning the losses from a past flood as well as providing information and education in the local area, for example through flood exhibitions or flood museums.

As this chapter is being edited, in Switzerland where the lead author lives, we are just undergoing our annual siren test to check the functionality of the civil protection alarm system and the sirens themselves. This is a well respected process in Switzerland. In Germany and other European countries, there was criticisms that the ability to alert the population quickly had diminished significantly over the past years and decades since the end of the cold war, in part due to the removal of sirens for civil protection purposes. There is an incentive program by the German federal government to rebuild or re-activate sirens again, with a total sum available of 88 million Euros for incentives towards their installation. Unfortunately, there currently is no clear mapping of where sirens are or would be needed nor an agreement who would be financing the operation or maintenance following the installation. However, reinstalling or upgrading the siren system is only one step for a well-prepared society. Information chains, familiarity with the scenarios to be dealt with, an appreciation of the roles that each organization and each individual can play to protect themselves or the local population, and an understanding of what relevant flood scenarios could be for the future are all required as part of a system of preparedness and early warning. This requires a dedicated information and training campaign, probably using existing "commemoration" days like International Disaster Risk Reduction Day on 13 October, or a specific Civil Protection Day nationally, where elements to achieve a higher level of population preparedness and coordination amongst the response and rescue organizations could be communicated and practiced each year. The existing, state and federal level protection exercises "Lükex" seem not to be enough.

An understanding needs to be created that these events are relevant for each and every one of us and that they are more likely to happen – they are not an unprecedented, unimaginable "Black Swan" event as has been said, but rather a risk to daily life that must be taken seriously and acted upon. This is a relevant and necessary minimum action in the space of climate change *adaptation* and disaster risk reduction. We have seen that the events following "Bernd" were quickly leveraged to discuss climate change – but mostly the urgency for climate change mitigation, especially in Germany, talking about accelerating the net-zero pathways for energy and mobility. This however misses the point that climate change effects are already here and will continue to increase, even if we were to hit the 1.5°C target. That discussion also left out more "traditional issues" in flood risk management such as rainfall infiltration and river management, land use planning, building codes, improved flood hazard / flood risk mapping, among many others. Questions are whether existing warning and planning instruments such as high hazard zones etc. are respected, whether they are adequate ("100 year flood zone"), and how we better adapt to a shifting flood regime. The Head of the BBK office urged that the planned reforms for civil protection could wait no longer. Their intended changes were going exactly the direction that was needed, but the speed of implementation would have to be increased. In 2020, the ministerial conference of the interior had decided to create a federal-state-competency center at BBK where all involved actors during a crisis could come together to collaborate and better coordinate, especially the response and recovery needs.

According to preliminary insights based on expert interviews and media reports, there were coordination issues during the emergency response, leading to inefficiencies over an initial period of time. The sheer scale of the event as well as some bureaucratic processes and structures were mentioned as challenges for bringing support to the affected areas. Anecdotally, communities 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. Response actors felt that they could act faster and more impactfully when working outside some of these structured and procedures. One reason mentioned was that the system no longer seemed used to such large-scale events, which requires coordination and expertise not readily available anymore. Other recent large-scale events such as the refugee situation 2015 or the Covid-19 pandemic required less coordination across fields of expertise and were managed by the respective subject matter experts. Another added layer of complexity for the response was the need to coordinate between district, state, and federal level layers of responsibility – both within and between organizations.

In Germany, another noteworthy feature of the response also seen in earlier flood events were the large numbers of spontaneous volunteers. Remarkably high solidarity in the population led to an influx of volunteers bringing both benefit as well as challenges to the response operations. While additional help was welcomed by the population and official response actors, this also brought several challenges such as more difficult access to affected areas as traffic blocked the roads, lack of coordination and resulting frustration between official and unofficial helpers, and the attempted politicization of the event and response by populist movements that emerged during the Covid-19 pandemic.

Generally, the Covid-19 context seemed to have not played an important role during the response. Case numbers were generally low during the summer and no worrying increases in cases were reported in the affected areas after the floods.

Recovery and Reconstruction:

There are very imminent needs for the population to be reconnected to critical services and to get to more permanent shelter, as more than 8000 buildings have been destroyed or are inhabitable and as tens of thousands of people were cut off from daily needs including telecommunication, drinking water and waste water and many other services. In RLP, most drinking water supplies could be restored within two months. However, sewage treatment plants in Altenahr, Mayschoss and Sinzig have been largely destroyed and it is currently unknown how long their reconstruction will take. In NRW, for example in the heavily destroyed town of Bad Münstereifel, drinking water supply was established within five days after the flood event (most frequently through emergency tanks), and about 50% of the city centre was re-connected to the fresh-water network shortly thereafter, however, water had to be boiled before consumption until about one month later, all of which were a significant impact for flood victims. The German Red Cross is operating two temporary water treatment plants in the Ahr valley that are planned to run for 3 to 5 years. Originally, they were planned to be put in use, together with the IFRC, for international operations (e.g. in Bangladesh). This is the first time they have been used domestically.

As to telecommunication, in RLP it took two weeks to ensure 100% coverage again through emergency communication masts. Within one month, most of the network had been restored to pre-disaster service provision. Within four months, broadband had also been restored in the most affected areas.

Similarly in Belgium, approximately 41,500 people experienced power outages at the peak of the event. This was the result of both damaged and deliberately switched off electrical cabinets to prevent serious damages. It took around three weeks to fully restore power. Severe damage has been observed to the gas network. In the villages around Liege, such as Chaudfontaine and Pepinster, gas supply was expected to be fully recovered within four months. Several towns experienced disruptions in water supply (in particular as a result of pollution). One week after the event, around 400 households had no access to potable water.

The extent and duration of these lifeline outages highlight the vulnerability of such infrastructure and the knock-on effect they have not only in the response phase where these services are absolutely critical, but also in the weeks and months following the disaster. We therefore identify another need for a flood risk-based approach to better understand where critical failure nodes for this infrastructure exist, whether they are exposed to flooding and if so, how vulnerable they are and what protection gaps exist. While this is not a new insight and has been reported by us in other large-scale floods[vii], it still has not been adequately addressed.

However, there is a much wider challenge around the long-term recovery needs, and where recovery is even possible. As part of the hydrological analysis of the floods especially in the Ahr valley, it is clear that flood maps need to be redrawn and partially they already have been redrawn to better understand where rebuilding of completely destroyed property should not be facilitated because the risk is simply too high. Where reconstruction is possible, the question of building back better needs to be addressed – a time critical element as there is an urgency and psychological necessity for people to enable a return to “normal life” but at the same time planning needs to be done carefully so risk is not locked in to the same level as before the event, but that any reasonable opportunity is used to build back better and reduce risk along the way.

Corrective risk reduction

The ability to protect people and assets in topographies with fast reacting rivers like the Ahr valley using more traditional, physical “grey”-type infrastructure-based protection systems is really limited. For one, the ratio between the space available in these narrow valleys and the volume of water to be retained locally is very unfavorable. It is hard to retain the excess water in a sequence of retention basins based on the scenario that unfolded in July 2021. Locally, many rainwater retention basins had been planned in several of the affected areas, including not only the Ahr but also the Inde and Vicht rivers (tributaries to the Rur). Originally there were discussions on the utility and feasibility of those generally, whereas currently the discussion has shifted to a more immediate need to implement them but understanding their protection limitations – against which amount of excess water they could protect, and at which point they would be overwhelmed, and how. For any corrective protection system like levees or retention basins, their levels of functionality and their mechanisms of failures must be clearly understood and designed accordingly. Catastrophic failure of protection infrastructure has been seen in many past flood events, leading to further catastrophic knock-on effect downstream to the extent that looking at total risk, they don’t provide good protection because of the large extent of damage they can cause for low frequency events. In the Ahr valley in particular, retention basins as the only or even one significant part of a wider solution will be very difficult to implement, will be cost prohibitive and not fit well into the landscape since they would need to be excessively big and high.

Flood protection needs to be looked at based on the topographic situation at hand, and in narrow valleys that have been densely populated in recent times, the volume of the flood per earlier discussions on hydrology and flood modeling must be understood first. Then, the origins of the flood depth locally must be analyzed, taking into account the natural and the built environment for these new flood regimes in summer. Roughness and blockages were decisive factors, and allowing a more regular flow of the water must be achieved using a combination of leaving space for the river where the risk is simply too high and where it is not advised to rebuild. Existing infrastructure along and across the river must be adjusted to account for the expected water flow – especially the cross sections of the many road and rail bridges. To achieve this, an overarching vision how to live with water is required at local and regional scale. This will impact the legal designation of construction and no-construction zones, where and how the city- or townscape can be developed, what space to provide to agriculture and recreation along the rivers, and what space the rivers get for themselves, including the use of nature-based solutions – any flood protection that does not require “grey infrastructure” is better than one that does, and any permanent protection – grey or green – is better than mobile protection for which adequate warning times are necessary. It also must be pointed out that large-scale flood protection by the state and federal level cannot be the only approach nor provide 100% safety. For over a decade now, in Germany the self-protection requirement of citizens is written into the national water act, but further awareness is still needed that some responsibility does lie with oneself and cannot be delegated to the government.

(5) Recommendations and conclusions

- While both the intensity of the rainfall as well as the antecedent conditions, especially soil moisture, were key contributing factors to the severity of the floods, a look back not even 200 years in history reveals that similarly big floods have occurred in the region of the 2021 summer floods. Land use planning, delineation of flood zones as well as flood preparedness and response must include these scenarios in future planning decision-making as relevant, realistic scenarios and not treat them as extremely unlikely outliers.
- The Ahr valley in Germany was most heavily affected. For areas in the Netherlands and in Luxemburg, it was a near miss. The question is not whether and when another flood of this magnitude could happen along the Ahr river, but whether other, similar geographies can learn the lessons from these floods and reduce risk now and increase their preparations for when such a flood will take place there. This is also relevant for flood protection, as efforts should now not be concentrated (and potentially overdesigned) where the event has just happened, but more generally flood protection needs to be strengthened in all high risk areas.
- The behavior of extreme floods may often be different from more regular and seasonal floods and may need to be treated separately in statistical analysis to better account for them and not treat them as tail events of the main statistical flood distribution. Here, the signal of these intense summer floods may be masked by the more regular and typical winter floods.
- The assessment of future flood hazard needs to take into account the non-stationarity of the weather systems including under the effects of climate change, the effects of dynamic effects in the hydraulic analysis including blockages from flood-borne debris as well as morphological changes in the river channel and the effects of the current and future built environment in narrow river valleys. Flood models need to be updated to reflect the latest knowledge in these regards to not significantly underestimate flood extents. It is also debatable whether "probable maximum flood" scenarios should be outlined to highlight what an extreme yet not unthinkable flood in the future could look like. There is too much discussion about events being "black swans" where in actual fact they were just not on the radar during non-flood times.
- For better planning, preparedness and response operations, and taking note of the societal and political implications of flood zoning for land-use and building permitting purposes, a set of different maps depicting various scenarios may be needed for these different uses. The flood hazard maps depicting the 100 year or similar decisive flood zone are for legal purposes. They need to incorporate historic information better so they more closely reflect reality. Additionally, rapid flood maps that follow early weather and flood warnings are necessary to better understand the extent of a flood situation that is developing to guide emergency measures as well as prioritize response and recovery mechanisms after the flood wave has passed. A legal flood map is not fit for emergency response purposes. Initial work has shown that such maps can be easily derived with relatively little computing power to make them swiftly available. Lastly, such maps are yet again different from ex-post mapping services that try to delineate the biggest flood extent based on remote sensing, mostly satellite data, which serve yet another purpose to best understand the location of damage and

humanitarian need, but which always will have to be produced ex-post with a certain time lag. All these different maps have their justification but need to work alongside each other with clear purpose and expectations.

- The end-to-end messaging chain of early warning systems needs improvement, from better clarity of roles and responsibilities in times of extreme weather crises to more coordinated use in input and timely dissemination of warning messages to the improvement of the messages themselves to make them more easily understood and actionable for the population. Speed and reach of early warning messages can be massively improved using 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). 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, potentially coupled with a single go-to civil protection warn app that has very high familiarity amongst the population and can serve as the single go-to point for further information and behavior/protection advice.
- Like in many PERCs before, we see that critical infrastructure was not robust or redundant and led to subsequent, cascading failures both in the emergency response and the later recovery operations. Telecommunication, road and rail access but also water and sewage facilities are absolutely essential for a society and for the support operations in crisis and they all too often fail catastrophically. The location, the construction and the investment strategy overall for critical infrastructure must be rethought to ensure these lifelines stay operational, as they are – as the name suggests – so vital for life.
- If society is going to continue to live in narrow, rapid-reaction, middle-mountain valleys, society may need to shift their perspectives about what living there could look like:
    - Grey infrastructure has hard limits, especially in these narrow valleys with high water capacity, so there is a need to incorporate nature-based solutions – leaving space for water along river banks, recreation, and agriculture, and accommodate this better and more stringently with fewer exceptions in zoning and land-use planning.
    - Adapt where and how construction for private property, businesses as well as critical infrastructure is permitted, especially within readjusted hazard maps that account for increased flood scenarios as mentioned earlier.
    - The floods in the Ahr valley have shown the limits of what physical and natural protection can achieve towards not just extreme but also “realistic-extreme” events. “Living with water” also includes knowledge building about the flood hazard, people’s exposure, and their vulnerability and what they can do before, during, and after a flood to accept certain damages will occur but that loss of life is avoided through corresponding behavioral and life-saving protective action, including an enhanced early warning system and messaging chain.
- The emergency response, particularly in the Ahr valley, faced challenges due to the sheer scale and complexity of the event and the actors’ unfamiliarity with this but also due to rigid structures and processes in the emergency management units. Digitizing these processes as well as trainings for and simulations of complex emergencies could help to build capacities for the future. These would not only prove useful for

future flood events but also for other large-scale and complex crises such as pandemics or refugee situations.

- In Germany, concepts for the collaboration between official response actors and spontaneous volunteers have been developed after the refugee situation in 2015, which saw a similar spike in solidarity and non-institutional volunteering. Yet, it has been reported that these concepts were not applied during the response to the flood. For the future, lessons learned from the flood response should be integrated in these concepts and dedicated focal points in the crisis unit and large response organizations could be appointed.

(6) References

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[i] Simonovic, S. P. and A. Peck (2013), Dynamic Resilience to Climate Change Caused Natural Disasters in Coastal Megacities Quantification Framework. British Journal of Environment & Climate Change, 3, 378–401

[ii] Keating, A., Venkateswaran, K., Szoenyi, M., MacClune, K., and Mechler, R.: From event analysis to global lessons: disaster forensics for building resilience, Nat. Hazards Earth Syst. Sci., 16, 1603-1616, https://doi.org/10.5194/nhess-16-1603-2016, 2016.

[iii] United Nations Office for Disaster Risk Reduction (UNISDR) (2015), Global Assessment Report on Disaster Risk Reduction, United Nations International Strategy for Disaster Reduction, Geneva.

[iv] Venkateswaran, K., MacClune, K., Keating, A., Szönyi, M. (2020). The PERC manual – Learning from disasters to build resilience: A guide to conducting a Post-Event Review 2020. Institute for Social and Environmental Transition – International.

[v] Junghänel et al. Hydro-klimatologische Einordnung der Stark- und Dauerniederschläge in Teilen Deutschlands im Zusammenhang mit dem Tiefdruckgebiet „Bernd" vom 12. bis 19. Juli 2021. Deutscher Wetterdienst, 21 July 2021. https://www.dwd.de/DE/leistungen/besondereereignisse/niederschlag/20210721_bericht_starkniederschlaege_tief_bernd.pdf

[vi] World Weather Attribution. Rapid attribution of heavy rainfall events in Western Europe, July 2021. https://www.worldweatherattribution.org/heavy-rainfall-which-led-to-severe-flooding-in-western-europe-made-more-likely-by-climate-change/

[vii] PERC Central European Floods 2013, Zurich Insurance Company, 2014. https://www.zurich.com/en/sustainability/people-and-society/zurich-flood-resilience-alliance/learning-from-post-flood-events

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