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# Editorial for the Special issue on “2021 Summer Floods in Europe”

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## 1 Introduction

The heavy precipitation along with the river floods of July 2021 was an extreme and exceptional event in several countries in North-western Europe. It had major societal impacts in the Netherlands, Belgium, Luxemburg and Germany and was one of the most disastrous flood events in Europe of the last decades.

It is very important to learn from these events to reduce future risks and enhance preparedness. In order to do so, it is important to analyse and evaluate the event and document causes and impacts. As a flood affects the whole society, a broad range of topics has to be assessed: meteorology, hydraulics and civil engineering, societal, economic, environmental and health impacts, and emergency management, governance. The investigation methods employed differ between the phenomena and impacts. For example, field investigations and measurements give information on erosion and pollution in rivers, high water levels, performance of flood defences and damage to structures. Models can simulate past flood events and weather phenomena as a basis for future prediction and risk assessment. Surveys, interviews and data analysis will give insight in longer term social, health and economic impacts.

This special issue of the Journal of Coastal and Riverine Flood Risk brings together studies that investigated different aspects of the summer floods of 2021 in North-western Europe. The core consists of a series of studies that were conducted directly after the event and focused on the floods and impacts in the Netherlands, but also includes follow-up studies from after the event and from outside the Netherlands.

**Keywords**

Floods, Northwestern Europe, fact-finding, impacts

## 2 Setting the scene: an unprecedented event

On Tuesday and Wednesday 13 and 14 July 2021, there was exceptionally heavy precipitation in the parts of the Meuse and Rhine catchment areas in Belgium, Germany and the Netherlands which led to the rivers (and tributaries) flooding in many places. The event was associated with a ‘cold-core low’, an area of low pressure with an upper-level cold pool of air that is cut off from the jet stream. This results in strong convection and attraction of moist air from a large area and due to its relatively slow movement (due to the cut off from the jet stream) this can result in a lot of precipitation in a limited area (ENW, 2021; chapter 2).

The 1- and 2-day amounts of precipitation, and corresponding discharges that occurred, are rare, especially in the summer season. Most of the precipitation in the Netherlands fell in the eastern part of South Limburg, with 48-hour values for 13 and 14 July of 158 mm in Schaesberg and 182 mm in Ubachsberg. Above the Ardennes in Belgium, 48-hour sums over 200mm have been measured at Jalhay and Spa. Most of the precipitation in the region fell on 14 July, mainly in Belgium and Germany. This amount of precipitation in this area is exceptional, especially for the summer period and in many cases the amount was unprecedented in measurement records (even those longer than 100 years). According to the precipitation statistics from KNMI/STOWA/HKV (Stowa, 2019) the probability of exceedance of the 48-hour total measured for Schaesberg is approximately 1:1000 years. Given the unprecedented nature of the precipitation totals, statistical estimates are very uncertain though. Estimates of return periods of the 2-day precipitation totals in various sub-catchments of the Meuse river also show very high return period, over 10,000 years, particularly when only considering summer data (when there is usually less extreme precipitation)(Table 1). A regional analysis issued by the World Weather Attribution programme (WWA, 2021) estimates that for most areas between the Alps and the Netherlands the return period of such an event is about 300 years.

Table 1: Return periods (years) for the 48-hour precipitation total that occurred in some sub-catchments affected, calculated for the summer period and the whole calendar year. Return periods have been calculated using a Gumbel distribution based on the E-OBS dataset. Calculated results have been rounded. Based on (ENW, 2021)

| Area | Summer period | Whole year |
|---|---|---|
| **Meuse** | > 10,000 | 5,800 |
| **Geul** | 1,500 | 1,000 |
| **Roer** | 1,800 | 540 |
| **Ambleve** | > 100,000 | > 100,000 |
| **Lesse** | > 10,000 | 9,400 |
| **Ahr** | > 10,000 | 3,800 |
| **Ourthe** | > 10,000 | > 10,000 |
| **Vesdre** | > 10,000 | > 10,000 |
| **Meuse FR** | 450 | 50 |

The record precipitation totals also resulted in record discharge on the Meuse river and some of its tributaries. At the border between Belgium and the Netherlands (Borgharen), discharge reached record levels. Again, determining a return period for this unprecedented discharge is subject to considerable uncertainty. Estimates based on observations are around 1/100 years. However, when again only the summer period is considered, return periods become very high (600 – 11,000 years) as normally high discharge occurs in winter. Strikingly, the observed discharge of July 2021 did not occur even in 50,000 years of summers synthetically generated by the GRADE toolbox; the standard toolbox used by RWS for calculating exceedance probabilities (ENW, 2021; chapter 2). In many ways, the conditions in July 2021 were unprecedented and therefor the event is important to analyse in order to improve risk management into the future.

# 3 The Netherlands: Post-flood fact finding studies

## 3.1 Background and approach

The most affected areas during the 2021 floods in the Netherlands were along the river Meuse, and its tributaries (Geul, Roer and Geleenbeek) – see figure 1 for an overview. Directly after the floods in July 2021, a broad consortium of knowledge institutes was commissioned by the Dutch Expertise Network for Flood Protection (ENW) to perform an exploratory fact finding study in the weeks after the event (ENW, 2021). The consortium was led by Delft University of Technology and Deltares, and consisted of researchers from HKV consultants, VU University Amsterdam, Utrecht University, KNMI, WUR, Erasmus MC and the University of Twente. The study focussed on collecting, documenting and analysing factual information that was publicly available. An evaluation of policies and organizations was not within the scope. The research team has used public data (e.g. water and rainfall level observations) and received information from responsible authorities, mainly Limburg Water Authority (Waterschap Limburg) and the Dutch Directorate General for Infrastructure and Water Management (Rijkswaterstaat). In addition, the research team has performed several field investigations in order to add visual observations and collect further field information. The datasets from the research included flood extent maps, and incidents and observations for levees and other water infrastructure and have been published in the 4TU Research data repository (Slager et al. 2021).

A timeline of the main events and impacts in the Netherlands is given in figure 2, further details for the various topics are given in the several papers in this special issue that address hydro-meteorological and hydraulic aspects, performance of flood defence infrastructure, economic damage, emergency management and health impacts.

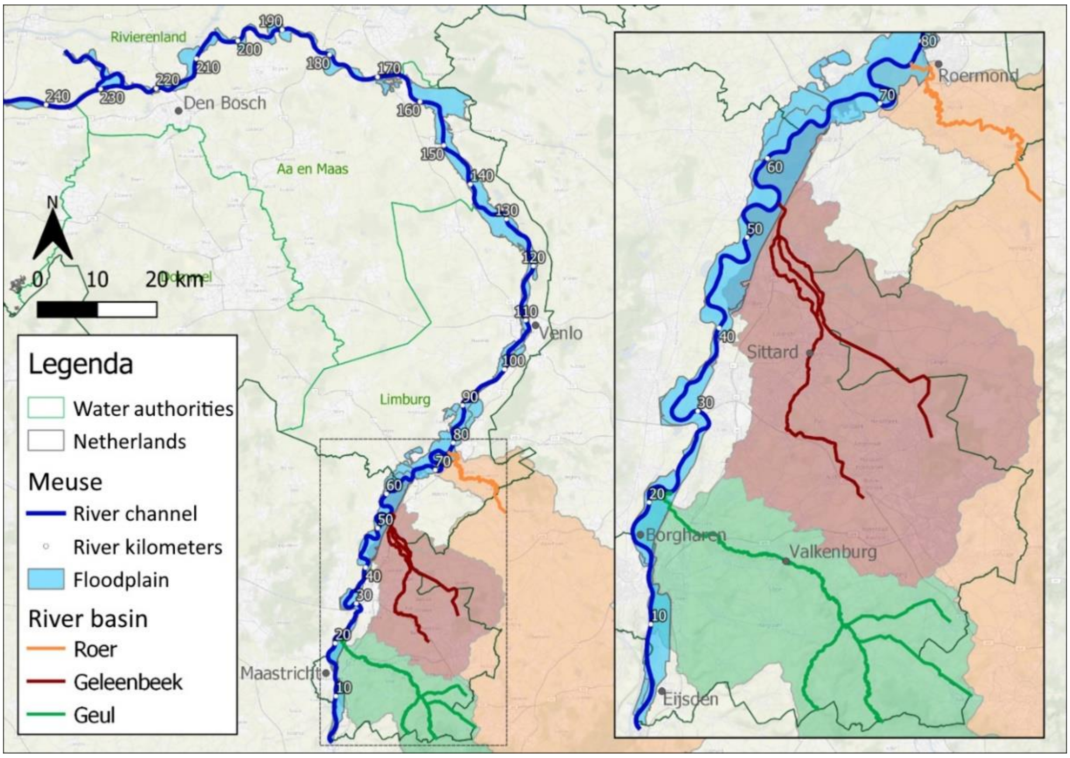

Figure 1: overview of the affected areas and river systems in the Netherlands.

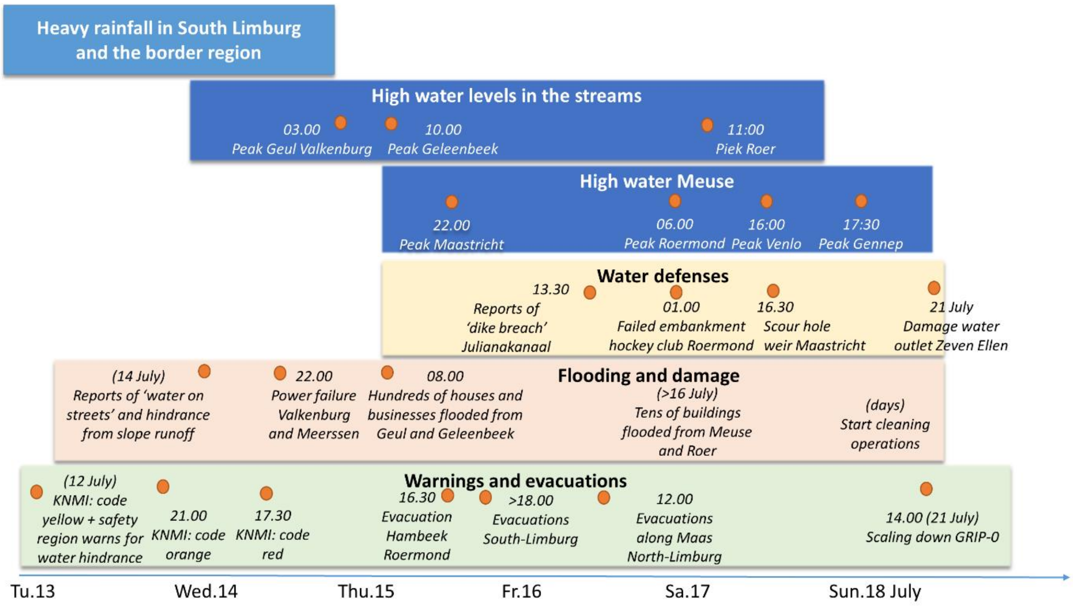

Figure 2: Timeline of main events during the summer of 2021.

## 3.2 Key findings for the Netherlands

The measured amounts of precipitation and river discharges have never been so large in this region, particularly during summer season. It is estimated that such an event occurs only once every 100 to 1000 years. The peak discharge on the Meuse River near Eijsden and discharge in a number of tributaries were the highest ever measured (Strijker et al., 2023). In total 2500 homes and 600 business have been flooded The estimated total damage due to flooding amounted 350 to 600 million euros, of which a substantial amount occurred in the river Geul valley. The damage was therefore greater than during the floods along the Meuse river in 1993 and 1995 (Kok et al., 2023).

The primary flood defences along the Meuse withstood the exceptionally high loads well. However, incidents such as piping (erosion of the sand under the dike) and local height deficiencies did occur in some places (Koelewijn et al., 2023). Temporary measures such as sandbags were therefore used on a large scale to stabilize embankments. Floods first occurred along the river Geul, and propagated towards the main Meuse channel and from there northwards in the following days. Whilst warnings did not always arrive in time in the Geul valley (contrary to the Meuse and Roer valley), overall around 50,000 people are estimated to be evacuated from the (potentially) affected areas. Citizens also took emergency measures, such elevating valuable possessions, lowering the damage that would otherwise have occurred. Half a year after the event, compensation and insurance was far from complete though, adding to the variety of predominant stress factors experienced by the people hit by the flooding (Endendijk et al., 2023). Not only physical damage was a concern, but also health impacts, particularly as the flood event took place during the covid-19 pandemic. Whilst the drinking water quality and supply was fortunately not negatively affected, a clear relation with an increase in psychological complaints (fear, stress, depression) was observed one month after the flooding (de Jong et al., 2023).

## 3.3 Flood impacts in other countries

Whereas the impacts were significant in the Netherlands in terms of economic damages, no fatalities occurred. The same flood event was more severe in Belgium and Germany. It caused billions of Euros in damage and hundreds of deaths in Germany and Belgium. There, the situation was more catastrophic than in the Netherlands, also because of the greater precipitation amounts and the steeper rivers catchments and valleys (Table 2). This resulted in more violent flooding and even shorter response and warning times (if any). The causes and circumstances of a significant part of the German fatalities, along with the role of warning and risk communication are discussed by Thieken et al. (2023b), showing the variety of processes that can lead to fatalities.

Table 2: comparison of the floods in the Netherlands, Belgium and Germany and their impacts (based on Chapter 8, ENW (2021)).

| | The Netherlands | Belgium | Germany |
|---|---|---|---|
| Rainfall (mm in 48u) | 180 | More than 200mm | up to 224 mm in 24 hr |
| Most-affected areas | Geul, Valkenburg | Ourthe, Vesdre, Meuse. | Ahr (Ahrweiler), Erft (Euskirchen) |
| Rivers: steepness (indicative) | 1% | 8 – 10% in Wallonia | 14% Ahr |
| Flood characteristics in most affected areas | Flood wave of ~0.5 m deep (Valkenburg) | Flood wave of several meters, mud flows | Flood wave, sometimes up to 4 to 5m deep, mud flows |
| Damage MEuro) | 350 – 600 (ENW, 2021) | > 2000[^] | 20,000 – 30,000 |
| Fatalities[#] | 0 | 43 | 196 |

# source for fatalities, https://en.wikipedia.org/wiki/2021_European_floods, accesses March 24, 2023.

^ https://www.vrt.be/vrtnws/nl/2021/10/27/schade-van-overstromingsramp-opgelopen-tot-ruim-2-miljard-euro/, accessed March 24, 2023.

# 4 Lessons learned

It is clear that this was an unexpected, extreme and unprecedented event. The findings from the initial studies reported in this special issue can be used for follow-up research, evaluation and for future proofing the system. Although these studies mainly concerned initial explorations, some lessons and recommendations can be formulated:

**Improve the predictions, flood warnings and crisis management** and their interfaces. The severity of the floods along the river Geul (Netherlands) and several rivers in Belgium and Germany was not anticipated, and insufficiently addressed in warnings (Thieken et al. 2023a) and emergency response. Better and more timely warning is needed to reduce damage and save lives. Apel et al. (2021) suggest that available models and data could have predicted the deadly potential of the 2021 summer floods. As a future direction it is important to develop and implement approaches that give a faster and more reliable warning, and to investigate how actionable warning messages can be communicated more directly and rapidly to the population at risk.

**Knowledge of river floods**: It is necessary to evaluate (the likelihood of) the occurrence of river floods in summer, including the effects of climate change. Studies by the World Weather attribution initiative (Kreienkamp et al. 2021) find that such events are expected to increase more frequently in the future. Also, the accumulation and interaction between floods in several tributaries should be considered. For example in the Netherlands, the combination of high discharges on the river Meuse and its tributaries (Geul, Roer) appeared to be largely unforeseen. Many observation stations failed during the onset of the 2021 floods, it is needed to implement observation stations that will remain functioning during extreme floods. Transboundary studies and collaborations for the affected rivers (e.g. Roer, Geul, Meuse) are needed to improve river management and warning.

**Impacts**: in order to improve damage modelling and the understanding of the effect of interventions, it is important to collect and analyse data for damages and compensations. The underlying drivers and factors (hydrological, social, economic) that determine the damage can be analysed from this information. It would be very valuable if authorities and insurers involved share damage data, and if a transboundary damage database will be developed for events like this. It is also important to evaluate and monitor the longer term economic and health impacts in the affected area. This event also give unique insight in the interconnectedness between different types of infrastructure (e.g. water, energy, transport) during extreme events, as well as the impacts of unforeseen compounding events – i.e. the combination of the floods and the Covid-19 pandemic.

**Infrastructure and flood defences**: the floods had major impacts on (critical) infrastructure such as bridges, power networks, dams etc. (Koks et al., 2022). The functioning of this infrastructure also had an impact on the floods, e.g. some bridges blocked part of the (debris) flow, and the operation of dams had major impact on downstream flooding. The event is also an opportunity to evaluate the effects of the measures that were in place before the floods – i.e. room for rivers and dike reinforcements along the river Meuse in the Netherlands. Moreover, the performance of the defences along the river Meuse under the extreme loads can be analysed (i.e. “proven strength”). The outcomes can be used to update the safety assessment of the defences, including knowledge of failure mechanisms, for instance based on observed cases of piping.

**Risk management, risk reduction and preparedness**: Particularly in the tributaries, the water system was clearly overwhelmed. Improved strategies need to be elaborated that include engineering, spatial and organizational measures to reduce the risk through a multiple lines of defence approach. As part of this approach, also land use and landscape-scale factors and interventions will need to be considered (Dietze et al. 2022). A recent study – also featured in this special issue – investigates the effects of various types of catchment interventions (reforestation, retention, river re-meandering) for the Geul river in the Netherlands (Slager et al. 2022). In some situations, e.g. river Geul in the Netherlands, safety standards may no longer be proportional to the damages, which should be evaluated through cost benefit analyses. Experienced floods extended beyond existing flood hazard maps and zones (Dewals et al. 2021) and revision of these maps as well as inclusion of more extreme scenarios (above design standards) seems needed. Finally, during the 2021 summer floods, locations such as nursing homes appeared to be vulnerable and mostly unprepared. In the development of flood risk reduction plans, other needs such as drought, ecology, housing and climate adaptation need to be addressed.

**Implications for other regions**. The extreme rainfall and flooding has surprised experts, water managers and citizens. It is important to assess what the effects of such extreme events would be for other areas in the Netherlands and Europe, and whether there is a need to implement additional measures. This special issue contains one paper (de Bruijn et al., 2023) that builds scenarios for other regions in the Netherlands. Exploration of such alternative storylines shows that the scale of the event would trigger extreme challenges for emergency response, potentially uncontrollable drainage in free-draining systems or widespread shallow flooding in areas dependent on pumping capacity.

Many of these topics need to be assessed in an international perspective – with Germany, Luxemburg and Belgium – as the water systems in this region are transboundary. It is therefore promising that both research communities as well as governments have started new transboundary initiatives to enhance the expertise and transboundary coordination. One recent example is the initiation of the EU funded EMfloodResilience within the Interreg programme to improve the collaboration and information exchange between Belgian, Dutch and German partners for improved flood management and the launch. Another important initiative is the launch in November 2023 of a Joint Cooperation programme for Applied scientific Research to Accelerate Transboundary Regional Adaptation to Climate Extremes (JCAR – ATRACE) with partners from Germany, Belgium, the Netherlands and Luxemburg.

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# Author contributions (CRediT)

All four authors contributed to this editorial paper.

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