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Lessons learned from Evacuation and Emergency Measures during the Summer 2021 Floods in the Netherlands.

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Abstract

In July 2021 catastrophic flooding has occurred in the south of the Netherlands, Belgium, Germany and Luxembourg. During this event various evacuation notices have been issued in the Netherlands. Over 50.000 inhabitants received the call to evacuate mainly along the Dutch parts of the River Meuse and tributary rivers as the Geul. In this paper, we will therefor chronicle the events related to evacuation and emergency measures, in order to draw lessons for future planning of emergency response related to flooding in the Netherlands. We have identified the relation with warning, different types of evacuation and discuss the role of forecasts.

Keywords

Flooding, Evacuation, emergency management, Summer 2021, Netherlands

1 Introduction

In the disaster management cycle, five phases are differentiated which can all contribute to reducing risk of extreme events such as flooding. These are: i) prevention, ii) mitigation, iii) preparation, iv) response, v) recovery (Brinke et al., 2008). Of these phases, the response phase is critical in reducing human suffering and casualties. Improved early warning and evacuation have been credited with reducing fatalities of extreme events in the last couple of decades worldwide (WMO, 2021). Given that extreme events do not happen regularly, the planning of it usually involves working with hypotheticals and procedures are ultimately tested when an event hits. In order to improve future planning of effective response to extreme events, it is therefore important to learn from actual experiences in order to inform procedures and plans going forward. In the Netherlands, the risk of flooding is substantial with a majority of the area being protected from primary water sources (major rivers, coast) by levees, or potentially affected by regional waterways and tributaries. There have, fortunately, been little large-scale evacuations in recent history, with the main event being the evacuation of ~250.000 people along the Meuse river in 1995 (Van Duin et al., 1995). Recently, in July 2021, catastrophic flooding has occurred in the south of the Netherlands, as well as in Belgium, Germany and Luxembourg. The record precipitation resulted in record discharge and water levels, putting pressure on water defences, causing damage and resulting in a whole range of emergency measures and evacuations (Figure 1). Fortunately, no fatalities occurred in the Netherlands, though they did occur in Belgium and Germany (Thieken et al., 2023). This event gives an opportunity to analyse how the Dutch response to the unfolding threat developed, and what we can learn from that going forward. In this paper, we will therefore chronicle the events related to evacuation and emergency measures, in order to draw lessons for future planning of emergency response related to flooding in the Netherlands.

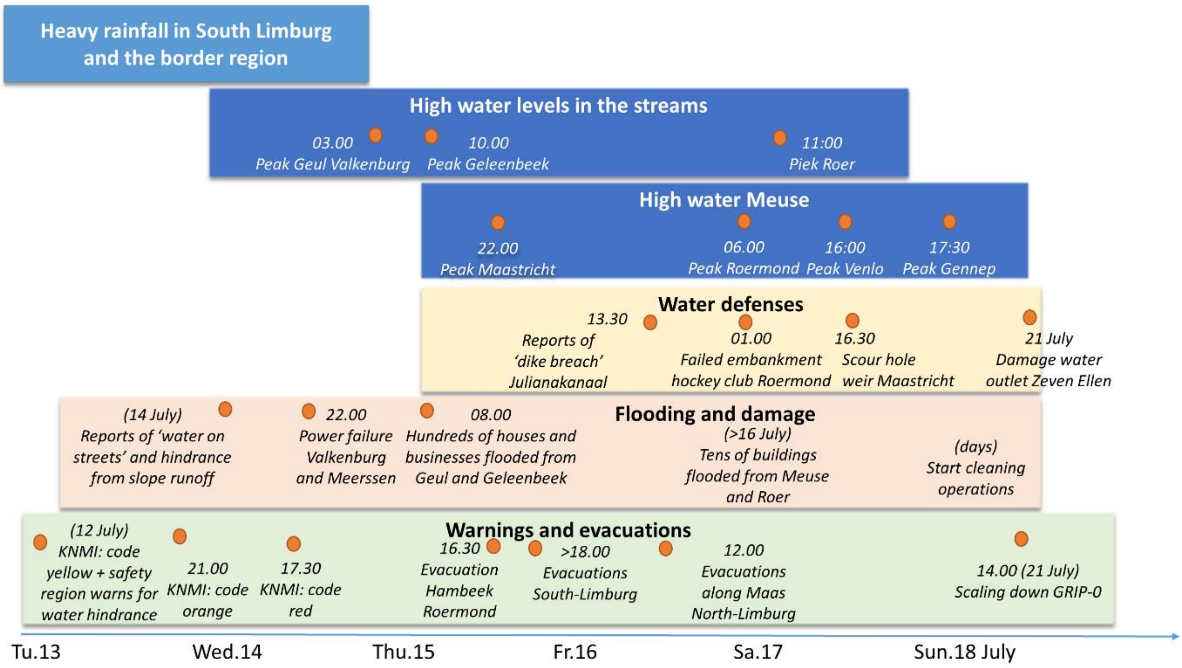

Figure 1. Timeline of main events during the summer flooding of 2021 in the Netherlands (after ENW, 2021)

2 Methodology

This paper is based on information gathered in the days and weeks (up to a few months) after the flood event in the July 2021 during the fact finding mission of the Expert Network Water (ENW) of the Netherlands (ENW, 2021). The information gathered comes from baseline reports of the LC-MS environment, which is the internal crisis management system of the Netherlands used by the safety region and water authorities. Moreover, public reports on liveblogs (e.g. from affected municipalities and safety regions), social media, and discussion with experts from Limburg Water Authority and people who were in the room and field were combined. An overview of social media used for this purpose is provided in the list below:

- https://twitter.com/VRZuidLimburg
- https://twitter.com/vr_ln
- https://vrln.foleon.com/vrln/vrln-verantwoordingsverslag-hoogwatercrisis-2021/tijdlijn/
- https://www.vrzl.nl/calamiteiten/code-oranje-vanwege-zware-regenval?calamity=1&ccm_paging_p=1&ccm_order_by=&ccm_order_by_direction=

- https://www.viecuri.nl/nieuws/2021/juli/liveblog-maatregelen-oplopende-waterstand-maas/
- https://nos.nl/collectie/13869/liveblog/2389373-dringend-advies-maastricht-aan-10-000-mensen-ga-je-huis-uit-dodental-duitsland-boven-55
- https://nos.nl/liveblog/2389253-hospice-en-verpleeghuizen-valkenburg-ontruimd-limburg-kan-even-ademhalen
- https://www.l1nieuws.nl/nieuws/1457162/teruglezen-spannende-uurtjes-in-well-bewaking-dijken
- https://www.l1nieuws.nl/nieuws/1454128/teruglezen-de-regen-is-gestopt-maar-de-maas-stijgt
- Liveblog of Waterschap Limburg (closed 14 October 2024: https://www.waterschaplimburg.nl/@9970/afvoer-weer-normaal-liveblog-gesloten/)
- Liveblog on floods in various municipalities (some had been taken offline after the event).
- https://www.youtube.com/watch?v=gBkmqHiS8rw
- If exact numbers of people are referred to, this is stated explicitly in the text.

This paper is structured through two sections: one on evacuation, and one on emergency management. In these sections the actions taken (through time) will be illustrated, the way decisions were made is explored, and how actions were implemented will be addressed.

3 Evacuation

Various forms of evacuation became apparent throughout the flood event. Evacuation along the river Geul (tributary of the main Meuse River) was initiated after the flood. People sheltered in houses but were trapped by the flood water. For the river Meuse emergency protocols were in place based on experience of flooding and evacuation in 1993 and 1995. Evacuation decisions along the Meuse were made by the local government based on risk assessments and flood predictions. In addition, some health as Sevagram and VieCurie Medical Centre initiated evacuation by themselves based on their own risk assessment using public available information.

Different types of evacuation can be defined (Kolen, 2013; Figure 2). The first parameter is the moment which is called for evacuation related to the start of flooding. Evacuation decisions can be made using forecast of the flood events (which is called a threat driven response), but as well during the flood event (called an event driven response). The second important parameter is the destination where people go to. Do the people leave the threatened area or seek shelter in the flood zone. The last parameter is the relationship between authorities (including) emergency services and citizens and private business. Preventive evacuation aims to evacuate the people out of the potential flood zone before the onset of a flood. In case of vertical evacuation people remain in the potential flood zone but move to shelters or safe havens in the flood zone. Shelter in place means that people shelter in their own homes. Acute evacuation is initiated after the start of the flood event, but before exposure (based on the arrival time). Rescue is defined as the removal of people out of the flood zone by rescue workers, escape as defined as removal of the people by citizens response.

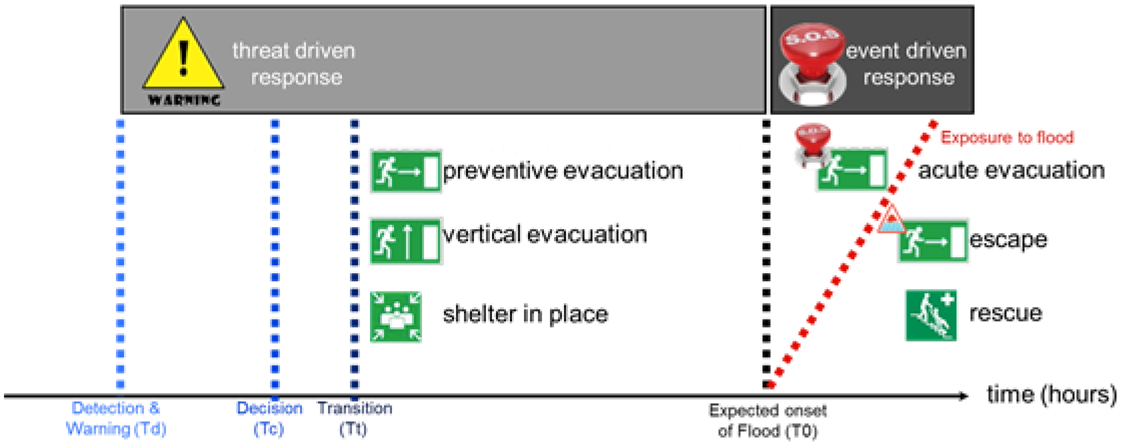

Figure 2. Different types of evacuations (Kolen, 2013)

3.1 Different rivers

We can distinguish different areas from the perspective of evacuation. The first area is around the tributary river Geul. This area can flood because of extreme rainfall in the catchment of the Geul located in the Netherlands and Belgium. In this area flooding occurred because water volumes exceeded the capacity of the water system which was designed to deal with 1/25 per year events. The areas around the Geul are not protected by levees. Existing emergency plans aim to warn camping areas along the river Geul in case of extreme rainfall.

The second area was threatened by flooding from the river Meuse. The river Meuse has a large catchment which covers part of France, Belgium and the Netherlands. The river enters the Netherlands south of Maastricht. More downstream the tributaries Geul, Geleenbeek and Roer join the Meuse. This area consists of unembanked areas (not protected by levees) and small dike ring areas which are protected by levees. After the flood event of 1995 al lot of measures have been implemented to reinforce levees and mitigate extreme water levels on the River (as Room for the River). In 2017 new safety standards have been defined for the levees, which should be met by 2050.

Around the Meuse, areas were preventively evacuated in order to ensure that no-one was present when flooding or the breaching of flood defences actually occurred. The time available for evacuation was an important factor in each case in order to prevent people from being exposed to flood water during the process of evacuation. Along the tributary river Geul (which flows through the city of Valkenburg), many people had to escape on their own and preventive evacuation notices were not given. Figure 3 shows the areas where there was an emergency ordinance.

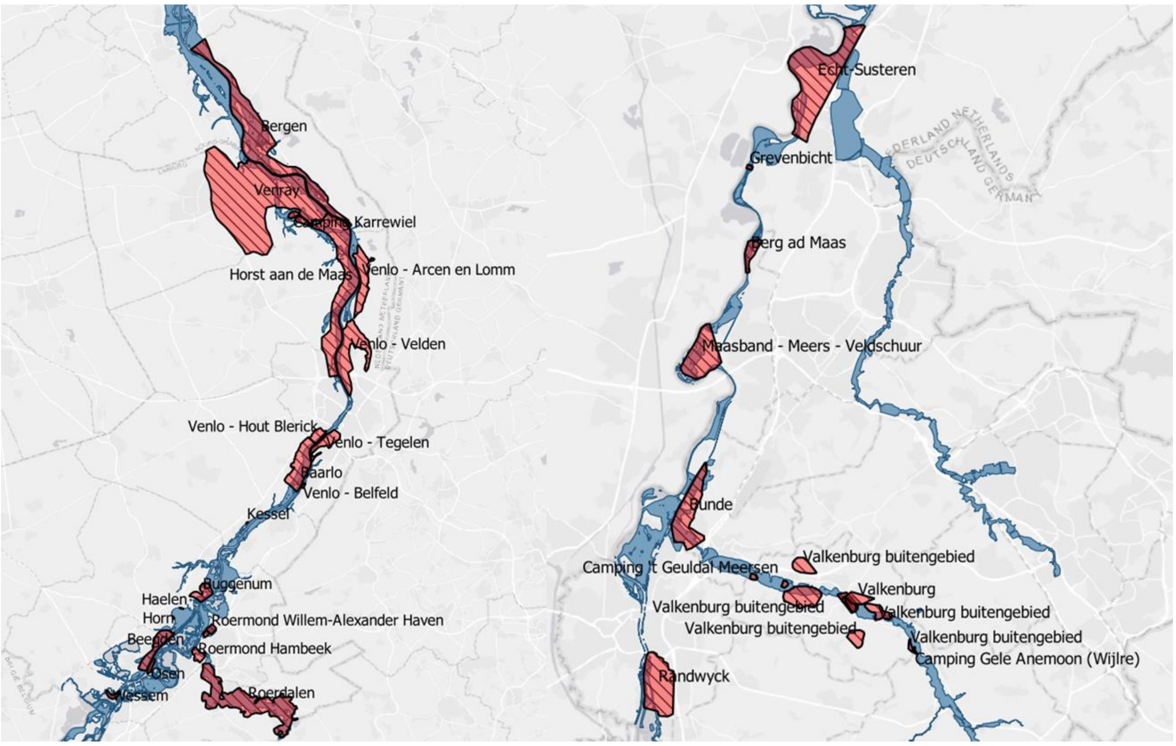

Figure 3: Areas where emergency ordinances were issued with regard to evacuation and disaster tourism (red). The contours of the area flooded are shown in blue. Left: North Limburg and North Brabant. Right: South Limburg.

3.2 Evacuation timeline

People living in the neighbourhoods around the Geul valley were mostly surprised by the floods during the night of 14 to 15 July, especially by how quickly the water rose. Only areas directly around the Geul (namely various campsites) were evacuated prior to the flood during the day on 14 July based on emergency protocols. These protocols (and underlying scenarios) and did not foresee in large-scale evacuation for cities as Valkenburg and Meersen. In Valkenburg and Meersen, a number of care institutions also evacuated preventively which they initiated by themselves.

The flood peak affected residents in Valkenburg in particular but also downstream in Meersen and along the Juliana Canal in the direction of Bunde and Geulle. Approximately 1000 people were exposed to the floods in Valkenburg and did not leave the area until after the floods. In two districts of Valkenburg, there was a power outage and despite those districts not being flooded, it was decided to carry out evacuation because authorities assumed a potential threat to become unlivable for the area. It is not known how many people actually responded to the call to evacuate. There was no large-scale evacuation in Valkenburg prior to the floods; here, people left the area after the floods mostly by themselves and sometimes with the help of aid workers. This is in line with the literature which indicates that in the case of natural disasters, between 60-90% of the people save themselves or get themselves to safety with the help of other people affected (Dynes, 1994 and Starmans & Oberijé, 2006). From the 15th, various emergency ordinances were issued in areas affected in the Geul valley, also to deter disaster tourism.

In contrast to the Geul valley, in the Meuse and Roer valley it was possible for more preventive action to be taken based on water level predictions and an inventory of weak spots and areas at risk. Because the water level predictions were changing in each case but also because more and more inspection results were becoming available, this inventory was also frequently adjusted. Based on this inventory, and particularly the one from 15 July, emergency ordinances were issued (regarding evacuation and disaster tourism) from Eijsden on the border with Belgium to Afferden in the north of Limburg. Sometimes those ordinances related to specific houses or streets, and sometimes whole districts that could potentially become flooded or cut off by the water. The way in which calls to evacuate were sent out varied from area to area depending on how the risk of flooding was assessed. In Venlo, the hospital also decided to evacuate as a precaution (just like it did in 1995).

Close to Bunde, it was feared that an acute breach of a dike along the Juliana Canal might happen (see also Koelewijn et al., 2023). For an area that included large parts of Bunde, Brommelen and Westbroek, it was initially advised to evacuate vertical (i.e. to higher floors) on account of this acute threat. There seemed to be not enough time for people to leave the area safely. However, that advice was quickly adjusted and people were urged to leave the area immediately (i.e. horizontal evacuation). That advice was not reflected in all media; some were still talking about vertical evacuation while others urged people to leave the area. This created a certain amount of confusion for people in the area and led to opinions being expressed on social media. It should also be noted that, prior to the announcement regarding the possible dike breach and the evacuation advice, there was already flooding in the area caused by water from the Geul and local rainfall. This area was also one of the last areas where people were able to return to their homes (not until Monday 19 July).

Table 1 provides an overview of the timeline relating to evacuation, warnings and flooding. In this timeline, a distinction is made between the moment of the highest regional phase of alarm issued by the safety region (called GRIP4) and the decisions made. The most decisive moments for evacuation have also been included. This timeline also includes where and when the floods occurred, the (start-up phase of the) warnings to the population, and finally the actual implementation of evacuation. The overview is not complete and only contains those evacuations for which the details are known. Although the choice to evacuate these areas was made early on, the evacuations themselves did not start any earlier than necessary.

Table 1. Overview of evacuations. KNMI is the Royal Dutch Meteorological Institute; RWS is the national Water authority; SR is the Safety Regions (North and South); WB is the Limburg water authority.

Time		Warnings and Flooding	Decisions and Evacuation	Approx number of people
12 July		KNMI: code yellow for rain tomorrow SR: high water levels Meuse and tributaries		
13 July		SR: repeat of warning for high water	SR: campings along Geul may need to evacuate	
	21:00	KNMI: code orange for rain		
14 July	8:00	RWS: floodplains of Meuse may be flooding		
	14:00		SR Limburg South to GRIP 4	
	17:30	KNMI: code red for rain	Campings along Geul are evacuating	
	20:30		SR Limburg North to GRIP 4	
	22:45	Start of flooding Valkenburg (Geul)	Preventive evacuation of care institutions Geerlingshospice, Oosterbeemd, Valkenheim (Sevagram 2021)	193
15 July	05:30	Peak water level Valkenburg	Preventive evacuation of 2 districts in Valkenburg without power	3750
	11:00	Loss of power for 700 homes Valkenburg	SR: drafting of evacuation ordinances; call on self-reliance of people	
	11:30		Preventive evacuation of the north and south side of Hambeek (Roermond)	750
	17:00		SR: ordinances established for evacuation and disaster tourism	
	17:30	Water has receded in Valkenburg	Preventive evacuation of Maasband due to the possibility of it being cut off by water (deadline 18:00)	1,500
	19:00		Preventive evacuation of parts of Eijsden-Margraten, Maastricht, Sittard-Geleen, Meerssen and Steijn	10,000
	22:00	Peak water level Eisen (along the Meuse)	Preventive evacuation of Bunde (Meersstraat, Weertenstraat, Maastrichterlaan and Kasteel Meerssen) and lower Geulle and Westbroek	2,250+
	23:00	Peak discharge at St Pieter of 3260m^3/s	Preventive evacuation of 2 districts in Echt	2,500
	night		Preventive evacuation of parts of Thorn, Buggenum, Beesel, Roerdalen and Roermond	10,000
16 July	09:00		Start Preventive evacuation of Venlo hospital (Viecuri, 2021)	237
	10:30		Preventive evacuation of 't Karrewiel in Meerlo (Limburg24 2021)	150
	14:00		Advice regarding vertical evacuation of Bunde, Brommelen, Westbroek and lower Geulle due to acute safety-related problem (piping Juliana Canal)	2,250
			Adjustment of advice regarding vertical evacuation to horizontal evacuation	ditto
	14:20		Preventive evacuation of Bergen and Aijen due to the possibility of them being cut off by water	500
	15:40		Preventive evacuation of Well, Wellerlooi and Heukelom (west side of N271, Vogelbuurt, Vlammertsehof and the Maasduinen State residential area)	1,500
	16:00		Preventive evacuation of Arcen, Baarlo, Lomm, Velden, Venlo, Tegelen, Steyl and Belfeld	15,000
	18:30		Tightening and repetition of evacuation advice for Well due to higher water levels	1,000
17 July	06:00	Peak water level Roermond (along the Meuse)		
	16:00	Peak water level Meuse at Venlo (Limburg North)		
18 July	17:30	Peak water level Meuse at Gennep (end of Limburg)		
19 July			Emergency ordinances withdrawn	
20 July			SR Limburg South back to GRIP 0	
21 July			SR Limburg North back to GRIP 0	

3.3 Threat appraisal and evacuation decision making

The Limburg water authority is responsible for advising the safety regions of Limburg on the threat presented by the water and for carrying out protective measures that reduce the flood risk. The safety region is responsible for decisions that affect public order and safety and for providing the population with information. The process starts with flood predictions. These are produced by both the Limburg water authority (for the tributary streams) and by the Directorate-General for Public Works and Water Management at the Dutch Water Management Centre (WMCN) which is part of the national water authority. WMCN's predictions relate not only to the water levels along the Meuse but also the discharge near St Pieter. Based on these water levels prediction the water authority makes an assessment about the strength of the levees and estimate the potential flood zone. For the regional water system, such as the Geul valley, the water authority is responsible to predict the water levels based on expected and measured rainfall. In this chapter we mainly focus on the river Meuse because in this area the decision for preventive evacuation were made (along the Geul evacuation happened while the area was flooded).

3.3.1 Forecasts of water level

Forecasts of discharges and water levels are by definition uncertain. To elements of uncertainty for the forecast of the river Meuse were important. The first element was the uncertainty of the forecasted discharge at the location St Pieter upstream in the river Meuse. This discharge was used to estimate water levels along the Meuse and for the assessment of the levees. The second element was the uncertainty the discharge of the tributary streams (Geul, Roer etc.) to the Meuse which was underestimated.

Peak discharge at St Pieter

During the first period also the forecasts of water levels (and dike failure) along the Geul and Meuse were very uncertain. These forecasts were based on the predicted discharge described by a hydrograph, Figure 4 shows the forecasted peak discharge at the location St Pieter which is upstream in the River Meuse. Until the moment of the measured peak discharge the forecasted discharge was underestimated. The forecasted discharge also holds uncertainty described by a bandwidth. Figure 4 also shows that the bandwidth on 15 July 16:00 is completely higher than the bandwidth of the forecasted discharge 8 hours before. The peak discharge was 3260 m^3/s during the night from the 15th of the 16th of July.

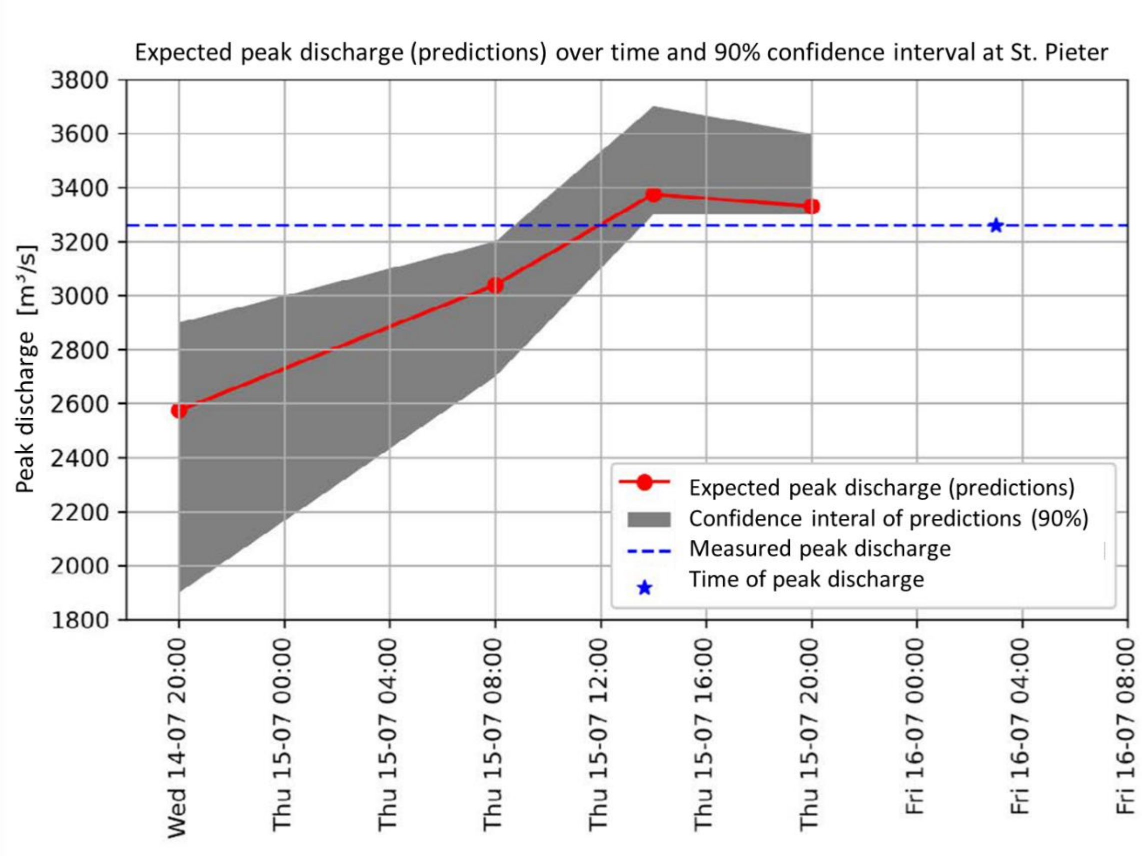

Figure 4: Timeline of predictions of the peak discharge at St. Pieter (border of the Netherlands and Belgium – source: ENW, 2021)

Tributary rivers

In the forecast of the WMCN the actual rainfall in the catchment of the river Meuse (upstream from St Pieter) was taken into account. The discharge of the tributary rivers was simplified in these models. Due to the actual extreme discharges from the streams, the Limburg water authority was afraid that this could lead to an underestimation of the water level. The Limburg water authority therefore carried out its own model simulations to use in addition to the forecasts of the Directorate-General for Public Works and Water Management. These forecasts of water levels were used to identify levees with a higher probability of failure (so called weak spots). The Limburg water authority used the Waqua model (version J18, the status of the Meuse works in the Netherlands and Belgium up to 2018 is therefore included) to estimate water levels resulting from the expected peak discharge of the river Meuse. The discharge of the Meuse was combined with a standard hydrograph of the Meuse system. This standard (winter) hydrograph corresponds with a long period of rain in the Meuse catchment and is generally used for policy decisions as room for the river and the design of flood protection measures which mainly focus on winter conditions. However, during summer 2021 the hydrograph was very peaked with a high but short spike in the discharge. During the event it turned out that the threat diminished downstream because in reality the flood wave on the river was not as broad as the standard hydrograph, which resulted in less extreme water levels downstream than predicted due to peak attenuation (Strijker et al, 2023).

The water level predictions issued by the Dutch Water Management Centre differed from the predictions of the Limburg Water Authority. The prediction by WMCN were also publicly available, but the communication by the safety region was based on the assessment of the Limburg water authority which created confusion.

In the afternoon of 16 July, it was decided by the safety region and waterboard to use the forecasts of WMCN as a basis rather than the estimates from the Limburg water authority. That means that the inventory of the weak spots in the levees after this moment was based on water level predictions for the Meuse drawn up by the WMCN, and in the days before based on the forecasts of the waterboard.

3.3.2 Weak spots in levees using forecasts of water levels

In accordance with its responsibility, the Limburg water authority carried out an inventory of weak spots in flood defences and the areas at risk along the Meuse. The areas where there was a significant probability of flooding were assigned code red, those where there was uncertainty were assigned code yellow and those which were deemed safe were assigned code green. This inventory was started before the peak discharge reached St Pieter and updated periodically after that. Those updates were carried out daily – up to twice a day – if new water level or discharge predictions were available for the Meuse. In addition, more information regarding strength of defences, field inspections and expert knowledge of specialists was always added with each update.

In the assessment of the levees two variants were taken into account related to the peak discharge at St Pieter (using the forecast of Waterboard Limburg):

1. A worst case variant based un the highest value of the bandwidth of the forecasted discharge taking overtopping of levees into account.
2. An expected variant based on the expected discharge taking not only overtopping but also geotechnical failure of levees into account.

Figure 5 shows the assessment of the water board of Limburg for a selection of the levees more upstream and downstream along the river Meuse for different moments. Note that from 16 July 13:30 the forecasted water levels of WMCN were used, RWS-H07 corresponds with the used forecast. Of course the moment of the peak discharge and the highest water level varies over time as also is shown in table 1. Figure 4 shows the impact of the forecasted water level for the risk class of a levee. Over time the risk was reduced because the peak discharge passed, but also because it became clear that the hydrograph flattened out more than expected on the 15th of July, particularly affecting the more downstream sections.

Dijk	18/07/2023 9:30 (H levels from RWS-H12)	17/07/2023 9:30 (H levels from RWS-H09)	16/07/2023 16:30 (H levels from RWS-H07)	16/07/2023 13:30 (H levels from Limburg water authority)	15/07/2023 (Expected discharge of 3350 m3/s - overtopping and geotechnical, H levels from Limburg water authority)	15/07/2023 (Expected discharge of 3700 m3/s - overtopping, H levels from Limburg water authority)
Visserweert						
Heel						
Olde Veste						
Merum						
Roermond Zuid						
Hockeyvelden						
Voorstad St. Jacob						
Arloflat						
Alexanderhaven/outlet						
Waterzuivering Roermond						
Buggenum						
Neer						
Baarlo						
Steijl						
Venlo						
Blerick						
Velden						
Gennep						
Heijen						
Mook-Ottersum						

Figure 5: Levee assessment by the water board at different moment, using forecasts of water levels of WNCN (RWS) and water board of Limburg. This figure holds a few levee sections, the remarks made per section are not presented. Source: LCMS of the water board of Limburg.

3.3.3 Evacuation decision

The making of decisions regarding evacuations was, according to protocol, done by the safety regions, based on the inventory of weak spots as supplied by the Limburg water authority, particularly from 15 July. In the run-up to the floods, the discharge predictions (and therefore the water level) varied considerably as already discussed and shown in figure 4 and 5.

In conjunction with the highest priority which was to protect people and animals, it was decided to evacuate areas that might flood (so not only the red but also the orange areas from the analysis of weak spots). Although the risk of flood defence breaches was extremely small for some, they were also evacuated as a precaution. Areas that were at risk of being cut off by the water (i.e. becoming surrounded by the water) were also evacuated.

That prediction used for the call for evacuation was thus based on the water level predictions of the Water Board itself. It was decided that mayors have the mandate to decide to evacuate and various emergency ordinances were drawn up. The evacuation notices corresponded a (strong) advice to evacuate, not a legal obligation (i.e. a formal clearing), though explicit efforts were made to evacuate as many people as possible. Not all evacuations were started at the same time on account of the duration of the flood surge, especially in the northern part, because it was not yet strictly necessary to start evacuating immediately. Although the assessment of the levees has been updated each 12 hours also on the 16th of July (based on WMCN forecast) the calls for evacuation had not been reconsidered. Even though for some areas the levee assessment showed that the probability for failure had been reduced.

The decisions regarding evacuation were shared via news reports and social media by the authorities concerned (municipality, safety region) and NL-Alerts, civil defence sirens and (in some cases) church bells were used. At locations with an acute threat (following the acute threat with respect to the Juliana Canal, for example), information was provided by the emergency services via PA systems on police vans. For the duration of the event, regional broadcaster L1 functioned as a ‘disaster broadcaster’ and assisted the safety region with communication. In addition to the formal central provision of information, a lot of information was also shared via informal channels (WhatsApp groups, family/acquaintances upstream) and people acted on that information. As a result, a lot of citizens’ initiatives resulted in local protective measures (see the section on emergency measures).

3.3.4 Evacuation implementation

One of the first decisions was to carry out prioritisation. This was based on the national priorities used for evacuation of the National Coordinator for Counterterrorism and Security (NCTV) but was now made more concrete. Attention was explicitly paid to the coronavirus crisis in this prioritisation too. The highest priority was the flood safety of people and animals. The 2nd priority was care, testing and vaccinating against the coronavirus. The 3rd priority was the continuity of the vital infrastructure followed by production processes (4) and economic interests (5).

An important starting point in the actions of the emergency services was to encourage people and institutions to be self-reliant. That meant that people (after they had been informed by the safety region) would evacuate themselves and organise any assistance and shelter – which is what happened in practice. There was no forced departure from whole areas. The general picture is that most people heeded the call to evacuate, acted in good time and vacated the area (see also Endendijk et al., 2023). No information is known regarding people who stayed behind or how quickly people vacated the area. For safety, the rescue team was present in the area to offer assistance if roads had become impassable due to the floods. Rescue teams from all over the country travelled to Limburg. The rescue teams also rescued stragglers here and there. Those actions attracted a lot of attention from the media in each case (see for example De Haan, 2021). But ultimately, there are strong indications that most of the stragglers vacated the area themselves or with help from other people.

The authorities did provide shelter for people but very little use was made of these facilities. Given the areas evacuated and the number of homes, the number of people residing in these areas is estimated at 50,000. The authorities concerned (municipalities and the safety region) and emergency services (police, fire service and defence) took care of communications.

The care institutions in Valkenburg and the VieCuri Medical Centre in Venlo were evacuated following consultation with the safety region because continuity was not guaranteed (the latter hospital was also evacuated in 1995). This consultation was initiated by the health care institutes. At VieCuri a total of 237 patients were safely evacuated from the hospital within 10 hours and the hospital remained closed for 4 days (Viecuri, 2021). 28 ambulances from all over the country were used for this purpose (De Limburger, 2021). That is almost 5% of the total number of ambulances in the Netherlands. The number of ambulances required for the whole of the Netherlands is estimated at 642 by the National Institute for Public Health and the Environment (RIVM, 2020). Some of the patients were able to go home while the remaining 170 were distributed between 28 other institutions. Evacuation was coordinated with the National Coordination Centre for Patient Distribution which was already active due to the coronavirus pandemic. The Maastricht University Medical Centre (MUMC+) was not evacuated because the threat was extremely limited. However, sand bags were put down as a precaution. The long term consequences to the people are not known yet, although the evacuation did not result in direct loss of life according to the VieCuri Medical Centre.

During evacuation, two burglaries were known by the authors at the time of the analysis. During the field visits, a number of local residents also indicated that the possibility for crimes to be committed was also taken into account when deciding whether or not to leave. The question remains of the number of crime was higher or lower during the event than during normal life. However there was no large-scale looting observed, which is in line with other major disasters and evacuations (Mileti & Sorensen, 2015).

4 Emergency Management and Measures

This section focuses on the implementation of emergency measures. These included both planned measures that had been prepared in roadmaps and unplanned measures (which we call emergency measures) that supplement each other. The planned measures consisted of temporary and removable flood defences that were constructed prior to the floods. The implementation of these measures is laid down in a roadmap and carried out by Limburg Water Authority and the municipalities along the Meuse. There were also (unplanned and temporary) emergency measures such as the putting down of sand bags because the defence was possibly too low or to create coffer damming of boils after inspections.

Limburg Water Authority was assisted by various experts from all over the country. Those experts were called in from fellow water authorities but experts from the private sector were also assisting. This increased the capacity for monitoring and implementation considerably.

4.1 Planned Measures

Limburg Water Authority has more than 4 kilometres of removable defences that have to be constructed as described in the roadmaps during a flood. That includes more than 200 mobile flood walls across the whole management area, these were planned in advance. During the period of high water levees also were regularly inspected. This resulted in identification of weak spots and new emergency measures which were not planned in advance. In addition, temporary flood defences were constructed at 23 locations, covering a total length of 2 to 3 kilometres. These temporary flood defences consist of approximately 2000 bigbags and 120,000 sand bags. A total of 140 pumps were installed prior to the floods in order to reduce excess water and seepage, amongst others. Finally, a large number of passages with valves (such as spindle sliders) in the flood defences were closed by the municipality and water authority.

Temporary flood defences

The setting up of these measures is a planned operation that is triggered by certain predicted water levels. Given the increasing discharge predictions, the decision was made to scale up to the highest phase and deploy all equipment. The maximum construction turned out to be necessary because the water levels came close to the retaining height of the removable walls when fully constructed. The period of time for construction normally specified in the roadmap is 5 days. Due to the rate of development of the flood wave, construction had to be carried out quicker. Construction began on Wednesday 14 July at 14:00 and the whole construction process was completed on Friday 16 July at 19:00. This involved working in phases: the lowest walls in the water column (which therefore must be sealed first) were built first and the higher defences were built last. Construction took a total of 53 hours (instead of 120 hours) and the work continued round-the-clock in continuous shifts.

4.2 Emergency measures

The emergency measures were realised based on an inventory of weak spots by experts from Limburg Water Authority prior to the floods, inspections carried out during the floods by dike inspectors, and initiatives of municipalities and local residents.

Prior to the peak of the floods (on Thursday 15 July in particular), Limburg Water Authority carried out inventory based on the weak spots in which vulnerable locations and emergency measures were identified. At locations where a controllable situation was expected, the amount and location of emergency measures was identified and implemented in anticipation. Emergency measures were also taken as a precaution in order to reduce the potential impact of any breach. Examples include the MUMC+ Hospital in Maastricht and the Bisschop Lindanus canal in Roermond. The amount of equipment and sand bags to be deployed was determined based on the continued updates of water level predictions and the local elevation of the assets.

4.2.1 Dike inspections

Some of the emergency measures were carried out following reports from dike inspectors. Inspections by dike inspectors were carried out on all primary flood defences. The frequency of inspection depended on the water level and was once every 4 hours during the peak for the most vulnerable places. The first inspection took place at sunrise (around 06:00) and the last at sunset and the start of the night (around 23:00 to 24:00). During the inventory by the water authority, it was found that there was a likelihood of sand boils at a large number of locations. For that reason, it was decided to carry out extra inspection rounds targeting these vulnerable places during the floods. In the process, dike inspectors were assisted by Red Cross workers in order to ensure extra capacity. Local residents were not employed for this due to legal considerations. Reports regarding the flood defences were sent via the dike inspection app or communicated by telephone to the control centre in Roermond. These were assessed by experts in Roermond and any measures were then passed on to the regional coordinators (called pilots) in Sittard for Limburg south and Horst for Limburg north. Implementation was then planned from the regional stations. In addition to the dike inspectors (more than 700 volunteers), some locations of special attention were also inspected by professional inspectors from the water authority who normally coordinate inspections and measures.

4.2.2 Implementing measures

The emergency measures were carried out through the joint efforts of the water authorities (Limburg Water Authority and the other water authorities in the Netherlands), municipalities, military, fire service and local residents. Measures were taken in order to strengthen existing flood defences but they were also taken along sections of the Meuse and the unprotected streams in order to prevent homes and businesses from being flooded.

Along the tributaries of the Meuse and along the streams (e.g. the Roer, the Geul and the Geleenbeek), emergency measures were mainly coordinated and carried out by municipalities and local residents (with the help of the fire service and the military). There are generally no (permanent) flood defences here. Temporary flood defences were therefore mainly used to limit the size of the area flooded and to prevent damage to homes and businesses. The majority of the sandbags along the tributaries (upstream sections) and the streams were put down by residents. The sandbags were often made available by municipalities and local contractors.

The emergency measures along the Meuse were targeted at height deficits as there was hardly any wind or extreme weather conditions. At a large number of locations along the Meuse, sand bags were put down in order to increase the retaining height of the flood defences. Because the water level predictions were available to the public and because of the visibility of the retaining height, municipalities and local residents made an important contribution to the initiation and implementation of emergency measures to increase the retaining height of the dike (usually sand bags on the crest). Sand bags were made available by the water authority, municipalities and local contractors. In some cases, residents used their own resources for the purpose of emergency measures. The sand bags, both along the tributaries and along the Meuse itself, were often made available by the municipalities at municipal sites and transported to the flood defences by local residents. Locally, this led to queues at the municipal site.

The Limburg water authority supervised deployment by giving instructions on how the sand bags should be put down. The manpower required was primarily supplied by local residents, military and the fire service. Due to the high level of self-reliance, the inspections carried out by the water authority (dike inspectors and inspectors) mainly focused on the geotechnical failure mechanisms.

During implementation, the provision of information, and coordination of emergency measures, Limburg Water Authority was also assisted by other water authorities who provided manpower and equipment. That included 3 sand bag filling machines, 100,000 sand bags, 500 bigbags, 10 trucks with containers, box barriers, 10 pumps and 20 roles of tarpaulin. In addition to the equipment provided, Limburg Water Authority was also assisted by 15 information coordinators and 30 inspectors from other water authorities.

Through their combined efforts, residents made an important contribution to the task of increasing the height of the defences along the Meuse (often along with the military or the water authority). It was possible for further direction to be given via social media and due to the presence of a number of professionals. Examples of this include emergency measures that were applied near Velden and Well. The bags were made available locally by the water authority and collected from municipal yards or contractors by residents. Sometimes they also used their own resources (bags or tarpaulins). Emergency measures that were taken by local residents were mainly aimed at increasing the retaining height of the flood defence. In some cases, measures were also taken by local residents in order to prevent geotechnical failure mechanisms such as piping (as was the case in Roermond, for example). The water authority supervised those measures as much as possible. In some cases, the application of emergency measures by local residents to the crest of the defence led to the shearing of the dike becoming a point for attention (due to the increasing weight on the dike). In those cases, the sand bags on the dike were then removed. Despite the fact that this sometimes even led to measures being carried out incorrectly (e.g. the stacking of sand bags on the crest of a weakened defence instead of behind it) and there was no total overview, the overall picture is that these extra measures increased the level of safety considerably.

Besides the official lines of communication via Limburg Water Authority, direct lines of communication were often established between inspectors, local dike experts present and the pilots in Horst or Sittard via WhatsApp, for example. A significant proportion of the emergency measures was therefore decided on without following the formal line of communication. For example, if the police, military and fire service were present locally, the lines to the water authority became short, decisions were made quickly and direct action was taken. In addition, app groups were often created by inspectors and experts so that information could be shared efficiently, they could keep each other informed and information could be handed over after shifts.

5 Concluding Remarks

Knowledge of the water system and the defences present is important when giving concrete warnings. The combination of a forecast, levees and a flood zone is the basic requirement for emergency planning, warning and evacuation. Along the river Meuse people have been warned and (largely successful) evacuated preventively. Along the river Geul people were not warned, and evacuated during the flood or after exposure.

Where disaster planning is often based on a number of (decisive or representative) scenarios which mostly follow from risk analyses of the water system, there is considerable diversity in potential scenarios as was shown by the summer floods. The precipitation event itself with the cold-core low, the steep flood wave and the rate at which the precipitation turned into discharge were exceptional. For the evacuation zones along the river Meuse numbers are not known regarding people who stayed behind. The picture is that almost everyone who was willing to leave also left the area in good time and found shelter. Those who did not made the explicit choice to do so, these were not limited by time. The care institutions and the hospital in Venlo were evacuated successfully.

People who stayed behind were mainly in areas along the streams that flow into the Meuse (and the centres along the Geul in particular) who were not warned. There were no casualties among those people who stayed behind, although they were at risk and anecdotes are known that almost resulted in fatalities. Most people were able to leave the area by themselves. Many also helped with the emergency measures that were carried out.

An important lesson learned is to use one forecast (model) of water levels and discharges and to have a set of more and less extreme flood events prepared. The flood extend and the probability of levee failure strongly depends of the shape of the hydrograph. There is no one scenario fits all as shown in this event, therefore we recommend of probabilistic approach of emergency planning with also explicit attention for worst case events. Scenario should not be focussed on a potential normative or design situation but cover a wide range of possible scenarios.

A second lesson is that all stakeholders have to agree on the model in advance, and to trust the forecasts produced. If the limitations of these models are known in advance it can also be prepared how to deal with them. This can only be done by preparation in advance in which all stakeholders accept the model and the limitations which are always there.

A third lesson is that the risk assessment of levees (and therefore the areas at risk) can vary over time. When more information is available the alarm code of levees can change from red (dangerous) to green (safe) or vice versa. During the event regularly new assessments have been made about the levees, but this new information is not used to stop (the start of) evacuation in some areas initiated during an earlier assessment.

Finally, we come to self-reliance as a fourth lesson. People evacuated themselves (after being notified) and care institutions were eventually evacuated with the help of colleagues after the decision was made to evacuate following consultation with the safety region. Citizens' initiatives, facilitated by the water authority and emergency services, proved valuable for the laying of sand bags. In the process, a lot of local app groups were also used in order to share knowledge and expertise and mobilise people. It is recommended to explore the possibility of making better use of that capacity and commitment from residents and businesses as an extension of the water authority and safety region.

In order to gain insight into the effectiveness of evacuation or emergency measures, it is desirable to collect more quantitative data. It is necessary to further develop the evacuation timeline, for example, distinguishing the decision to evacuate, when people received the message and from whom, when they left their homes (and how many people stayed behind and why), what their destination was and how long it took them to get there, how they got there and when or how they can return. It would also be of interest to formulate such a timeline for the taking of emergency measures, both by the water authority itself and through citizens' initiatives.

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Author contributions (CRediT)

All authors contributed to the fact finding and writing of this manuscript.

Data access statement

The data acquired in the study will be made available on request.

Declaration of interests

The author(s) report(s) no conflict of interest.

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