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Rapid damage assessment caused by the flooding event 2021 in Limburg, Netherlands

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Abstract

The floods in the Netherlands in the summer of 2021 led to severe economic damage and losses in the affected area. A first estimate in September 2021 showed that more than 2,500 houses, more than 5,000 inhabitants and around 600 businesses were affected. Using the Dutch standard Flood Damage and Loss Model (SSM2017), and based on figures from international literature, the total damage in the Netherlands is estimated in the order of € 350 – 600 million. Physical damage to houses and businesses, business interruption, damage to infrastructure and crop losses were the most substantial. The differences in damage to individual structures (residential and commercial) were large. The estimated damage in the affected area clearly exceeds the damage of the Meuse River floods in 1993 and 1995 which occurred in the same region (converted to 2021 prices: around € 200 million and € 125 million, respectively, excluding damage due to business interruption). It is important to note that the largest damages and losses in 2021 occurred in the smaller regional rivers, mainly in the Geul floodplain, while in 1993 and 1995 most damage and losses were recorded in the Meuse floodplain.

This paper aims to improve the preliminary damage estimates made immediately after the floods in 2021 by comparing them with actual damage reports from insurance companies and information acquired for the implementation of the national Act "Compensation of damage due to disasters" (WTS). We conclude that the value of the damage is about € 400 - 500 million, which is in line with the initial estimate. However, we observe a gap between the (lower) assessments of damage by experts and the (higher) damage as perceived by citizens and companies.

Keywords

Flood damage data, rapid assessment, updating with new damage data

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1 Introduction

In July 2021, large areas in the province of Limburg in the Netherlands were affected by extreme rainfall and floods. Also, large parts of Belgium and Germany were flooded, which led to high damages. Precipitation accumulated to 160 to 180 mm in two days over a large region. Similar heavy precipitation events in this area are rare and, furthermore have never been registered in the summer season. The probability of occurrence is much smaller than can be directly derived from observations of past events, although a combination of measurements from past event with a large ensemble of model simulations indicates that the probability of the Meuse two-day rainfall and peak discharge to be around 1:100 to 1:1000 per year (ENW, 2021). These probabilities are based on point estimates, the spatial distribution of the 2021 event has never been seen before, and therefore the probability can only be roughly estimated to be < 1:1000 per year. The main land use in the hilly area in Limburg is agriculture, but also some towns (for example Valkenburg) were flooded. Along the Meuse the discharge at the border with Belgium was never seen to be so high, and is estimated at 3200 m^3/s. (ENW, 2021) The Meuse discharge at the Dutch- Belgium border was the highest on record, but along this river there are levees. Fortunately, also because of intensive emergency measures, there were no breaches.

Assessing the economic impact of a flood event is important to reduce future damages and enhance flood risk management decision-making. Different methods have been employed in the past to assess these damages, including expert building visits (e.g., Wind et al., 1999), flood damage models (e.g., USACE, 2006), telephone surveys (e.g., Thieken et al., 2005) and remote sensing techniques (e.g., Tay et al., 2020).

The floods in Limburg are considered an extreme event with high impact. In the wake of such natural hazards, there is often a need for an indication of the damage to aid rescue and relief efforts and mobilize resources for recovery and reconstruction after the event (De Bruijn et al., 2022; WB, 2011). This is done through so-called preliminary or rapid damage assessments. There is a variety of methods available to do this, each with their advantages and disadvantages. In the US, FEMA has set up federal guidelines for initial and preliminary damage assessments by local governments through collecting on-site object data using standardized digital damage survey templates and visual inspection (FEMA, 2021). Similarly, the Asian Development Bank and World Bank performed a preliminary damage analysis in the wake of the 2011 Pakistan floods (WB, 2011), gathering and checking damage data from local governments in the context of a damage and needs assessment. Relying on direct observation requires, however, substantial (human) resources and a considerable amount of time. Various efforts are therefore made to support this process. For instance, the World Bank set up the GRADE (Global Rapid post-disaster Damage Estimation) methodology to give a first quantification of damage in a few weeks after a disaster using risk modelling techniques and high-level data such as satellite imagery, drone footage and social media (Gunasekera et al., 2018). De Bruijn et al., 2022, used social media footage (e.g., Youtube) of drone imagery to quantify the damage done by hurricane Dorian on the Bahamas and update vulnerability curves for the region. Drone and satellite footage was also used by Jiménez-Jiménez et al., 2020 to develop rapid urban flood damage estimation. They did so by comparing high-resolution before and after images of the impacted area and identifying buildings that were destroyed. Rapid assessments through risk modelling are also developed in Europe, where advances have been made to link the real-time operational flood forecasting system (EFAS) with a hydraulic flood and consequent damage model (Dottori et al., 2017).

All these examples of preliminary rapid damage assessments are bound by available (human) resources, pre-made models and observational data, and the method to employ in a specific event thus heavily depends on the circumstances. In the case of the 2021 floods in the Netherlands, the flood impacts occurred in both the main branch of the Meuse River, as well as in various tributaries. These tributaries are not typically included in the national flood forecasting and modelling system, and management is the responsibility of local water boards rather than the national water authority. As such, there were different situations with respect to data and management within the affected area. We therefore resorted to a damage modelling approach for a preliminary damage assessment of the 2021 floods in the Netherlands, informed by both modelling output (for Meuse flood extend) and remote imagery (orthophotos for tributaries). The damage model suite used (SSM-2017, see Slager and Wagenaar, 2017) is the same as is used in the more strategic national risk assessments. At the time of writing (2 years after the event), a more empirical estimate is also available. This allows us to test the preliminary assessment and the accuracy of the national damage model. For the preliminary assessment, field visits have been performed between July and September 2021. Whilst this only pertains to a small sample of locations, it does provide important context on how the event was experienced on the ground.

In this paper, we will limit ourselves to a damage assessment for the Netherlands, where only a small amount of damage occurred in comparison to Germany and Belgium (see for example Koks et al, 2022). Moreover, unlike Germany and Belgium, the disruption in the Netherlands did not claim any direct casualties, but the conditions at certain locations along the Geul were so extreme that they could have happened. There are numerous anecdotes of close calls. By 'extreme conditions', we mean high flow rates, water depths of more than 1.5 meters and situations where the water rose at higher rates.

A quote from an entrepreneur from Valkenburg illustrates the critical circumstances: *"The water was flowing insanely fast. I waded through it as I live 500 meters away from my shop, on the other side of the water. The water was waist high, and I could feel the current against my legs and I thought: get out, because if you fall here, you won't get out alive."*

In December 1993 and January 1995, Limburg was also hit by floods in the unprotected area of the Meuse River. One large difference compared with the event in summer 2021 is that back then, less damage was caused along the tributaries of the Meuse (such as the Geul and the Roer). In summer 2021, the peak discharge from the Meuse near Borgharen was comparable with the peak discharge in December 1993 and January 1995 (Strijker et al., 2023). The damage along the Meuse in 1993 and 1995 amounted to ~200 and ~125 million Euro (converted from Guilders to 2021 euros). The Act on Compensation for Damages (in Dutch: Wts, see Wts, 2021) was not applicable yet in 1993 and 1995 (it be-came applicable in 1998), but most of the damage was compensated by the Dutch government.

The floods in 2021 led to material damage to buildings, properties, and crops and to other types of damage such as business interruption. There are also consequences which are not as easy to measure and cannot be expressed in monetary terms, such as stress and loss of personal belongings with emotional value. Table 1 provides an overview of the types of damage that are distinguished in literature. The focus of this paper is on the damage that can be expressed in monetary terms, because the damage compensation schemes are targeting such categories.

Table 1: Classification of flood impact. Based on Kok et al., 2005.

	Can be valued in monetary terms	Cannot be directly valued in monetary terms
Physical damage	Capital loss (homes, property, crops, vehicles, factories, buildings and stock) and clean-up costs	Casualties, stress, ecosystems, pollution, monuments and cultural loss
Economic losses	Loss from production downtime, loss of income and disruption of vital functions	Social disruption, emotional damage, and inconvenience due to disruption of infrastructure

The aim of this paper is to explore the value of rapid assessment immediately after the flood: can with limited data a reliable estimate be made? In order to investigate this, the first assessment -conducted within one month after the flood events- is compared with damage data from insurance companies and other data sources. The novelty of this study is that the quality of the model-based rapid assessment is compared with flood damage data from the field, which is collected by damage experts.

This paper starts with an overview of the flood event, accompanied by qualitative insights into the resulting damage (Section 2). Subsequently, we delve into the process of deriving an indicative flood map for this event, followed by its application in producing an initial damage estimate using the SSM2017 national flood damage model (Section 3). To enhance the depth of the analysis, we compare these damage estimates to those of the Meuse floods in 1993 and 1995. Finally, we present an updated assessment on the flood damage, incorporating updated information that emerged after the initial assessment (Section 4).

2 Short overview of damages

Obviously, the main factor that led to the major damage was the enormous amount of rainfall in Limburg, the Ardennes, and the Eifel. This precipitation and the runoff from slopes led to significant consequences such as damage to homes, shops, hotels, and restaurants, but also damage to crops and recreational facilities, e.g., camping's, water sport facilities, and an amusement park (ENW, 2021). Also, water management infrastructure (sewerage, shores, walls, culverts, weirs, bridges) was damaged. The rainfall resulted in extremely highwater levels and discharges in both the Geul, Geleenbeek and Roer tributaries and the main river Meuse (Figure 1). During this event, the flood damage caused by the smaller tributaries, and the Geul in particular, was more severe than damage along the main Meuse River.

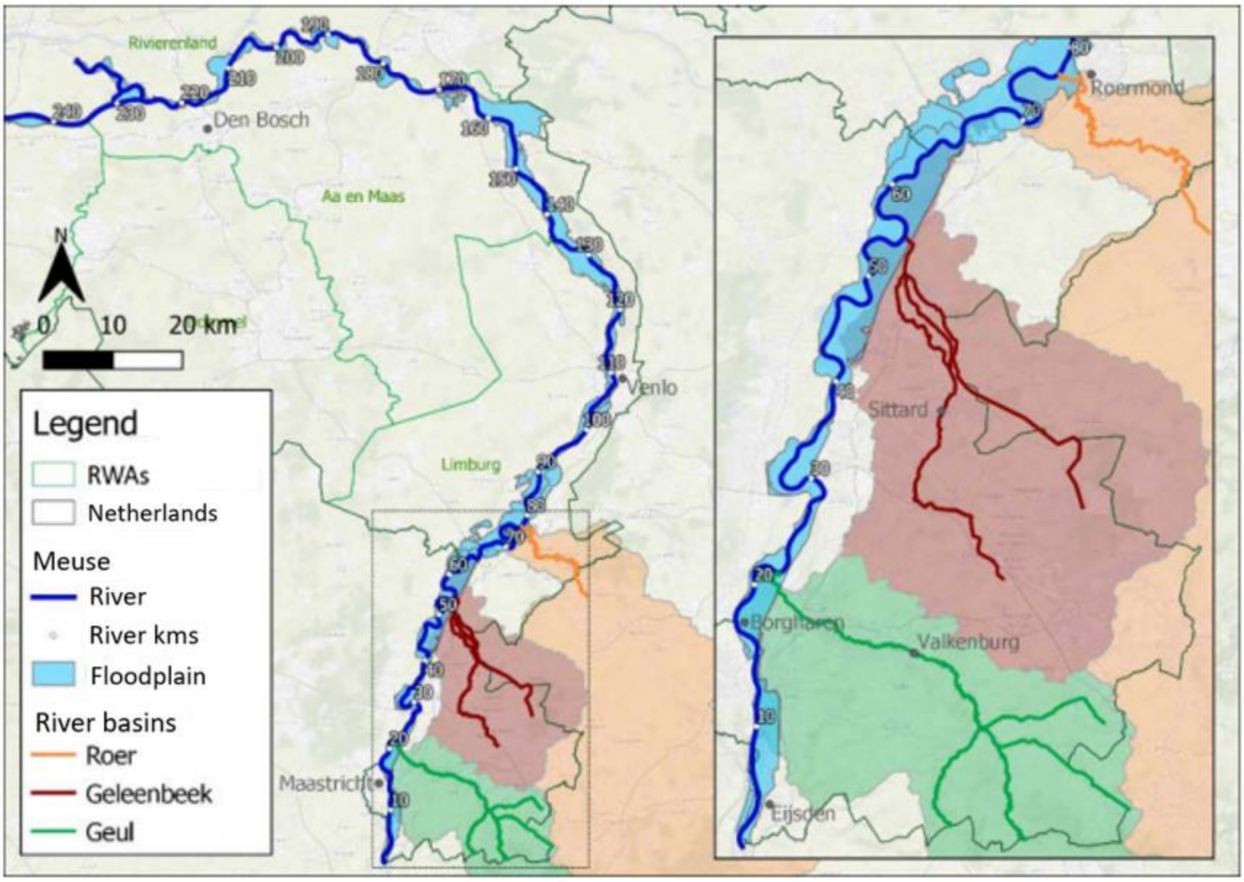

Figure 1: Map of the affected area with the main Meuse channel (in blue) and the catchments of the tributaries affected (in green, red and orange). Source: ENW, 2021.

The severity of the damage differs between locations and depends on the flood characteristics and the vulnerability of the area affected. In this case, the main determining factors were the water depth, arrival time and sometimes flow rate. Most damage occurred in the villages along the Geul. The severity of the damage differs widely between individual residences and individual businesses. The duration of the floods was short (1 day) but the recovery time is long for buildings and household items, which take a long time to get dry. The drying time for buildings depends on the type of building (such as type of floor and wall). The type of building therefore determines not only the direct physical damage but also the damage due to economic losses. Some flooded catering businesses reopened after just 2 weeks while others did not expect to open again until January (6 months after the event). Economic losses also depend on the availability of specialists and contractors in the area; various sources in local newspaper confirmed that this was a limiting factor in the period after this specific flood event. This scarcity resulted in longer waiting times (and associated losses) and higher costs compared to a normal situation when there is no shortage of labor and materials.

Apart from a few bridges in Valkenburg that were destroyed, there was modest direct damage to utilities and transport infrastructure: the outages of vital functions (transport, electricity, gas, and telecommunications) lasted less than a day. However, full recovery took over a week to a few weeks (Koks et al., 2022). Because the utilities and accessibility were only disrupted briefly, if at all, repairs could be started immediately. The short downtime of utilities therefore limited the cascading impact of the floods.

The damage was also influenced by the season in which this event occurred: in summer. Because this level of inundation and flooding is certainly not expected in the summer, residents and authorities were less prepared and residents had hardly any time to move their furniture. In addition, authorities had less time to carry out emergency measures or assist with evacuations. In the Geul valley, the forecasts and warnings came very late or not at all. The damage to agriculture, campsites and leisure facilities was also higher because in the summer, a lot of areas along rivers and streams are in use, while in winter, they are not used intensively because then flooding is considered more likely.

3 Initial assessment after the event

In the direct aftermath of the flood, we made an initial damage assessment based on constructed flood maps and damage assessment models. Figure 2 presents an example of the maps used to assess the flooded area, and figure 3 shows an impression of flooding and damage to the city of Valkenburg.

Figure 2: Example of the identification procedure of flood extents for damage assessment. The left picture shows a rural area along the Roer tributary in normal (dry) conditions (Source: ESRI). The right picture shows aerial photographs with retreating water after the flood event (Source: Het Waterschapshuis). Those pictures, together with existing model simulations (published on official government hazard maps – Source: Waterschap Limburg) are used to delineate the flood extent (red dotted line). Based on: https://storymaps.arcgis.com/stories/7488a4903f47499a9f765a23619eb2f4

An initial quick scan by the Netherlands Enterprise Agency (RVO, 2021) gave an estimate (maximum possible direct, material damage and costs) at the beginning of August 2021 that amounted to more than 1.8 billion euro. This was based on a rough estimate of 230,000 homes and 60,000 businesses having been affected. This is substantially higher than our initial assessment (this section), and later refinement (section 4).

The number of homes, residents, businesses, infrastructure, and land use affected were determined based on these flood maps (see Table 2). Most of the affected homes, residents and businesses were located in the catchment area of the Geul, and the highest amount of agricultural damage was along the Meuse. This preliminary overview is primarily based on the best possible determination of the flooded area (Figure 2), combined with detailed, up-to-date GIS registrations for exposed assets and land use (including Basic Registration Plots 2019, Basic Registration Addresses and Buildings 2021, Risicokaart.nl 2019 and National Monuments 2019). The water authority received many reports of flooding relating to water and mud in homes at the bottom of slopes, spread throughout South Limburg. Such (pluvial flood) incidents partly happened outside the flood extent that we were able to reconstruct.

Figure 3: Impression of damage in the city of Valkenburg (source Wikimedia).

Table 2: Number of residents, objects and institutions affected in the flooded area.

Category	Geul	Roer	Meuse	Total
Homes	2000 - 2400	60 – 75	300 - 400	2360 – 3000
Residents	3840 - 4160	60 – 120	500 - 600	4400 – 4880
Companies	390 - 400	10 – 15	190 - 200	590 – 615
Agriculture (ha)	700 – 725	925 – 975	9500 – 10,000	12,000 – 12,500
- pasture	73%	54%	60%	59%
- arable land	27%	46%	40%	41%
Vulnerable institutions	78	8	72	158
- care / education	12 / 5	0 / 0	2 / 0	15 / 5
Industrial emission installations	0	0	1	1
National monuments	60	8	68	136
Sewage plants	1	0	1	2

We estimated the damage using the regional and flood plain module from the Standard Method 2017 (SSM2017) Flood Damage and Casualties (Slager & Wagenaar, 2017). SSM2017 requires at least a water depth grid, which was derived from flood extent observations (Figure 2) combined with existing flood hazard model runs. For the tributaries of the Roer, Geleenbeek and Geul, aerial photographs were taken (particularly of the Roer) during the event, showing inundation directly, or shortly after the event (one or two days) showing flood marks and reconstruction activities. Based on this imagery and aided by elevation data and existing model simulations (see LIWO, 2022) flood extents were digitized for these three tributaries. To construct an indicative water depth map, model simulations (with a return period of 1/1000 years) were used as water depth input for the damage estimation with SSM2017. We verified the flooded extent of the existing 1/1000 year modelled scenario (spatial resolution of 5x5 m) by visual inspection. To get a first estimate of the total damage, we manually adapted this input water depth map, by excluding small areas not being flooded in reality. On the other hand, small areas that were flooded in reality, but not as such in the model results, were added to the flood extent and maximum water depth. An indicative water depth value of 0.5 m was used for these areas The peak discharge of the 2021 event was in the same order of magnitude as the discharge in the model simulation. Note that there are 4 rivers in de study area (Maas, Roer, Geleenbeek and Geul) which were modeled. For the main Meuse River flood extents, a similar approach was used, although due to a delay in the availability of the photographs, first a set of model simulations was used for water depth estimation, later amended by a visual check on flood extents from the aerial photographs. The optional input for SSM2017, such as the flow velocity, arrival time, or the rate at which the water level rises become of relevance when casualties are also considered. Since this was beyond the scope of damage assessment, and this data unavailable, they have not been used in the assessment.

SSM2017 uses a set of damage categories, which in this damage assessment have been grouped into the most relevant categories for this flood event: housing, businesses, crops, recreation, infrastructure and other. The damage categories are derived from different sources (Slager, 2016). For the businesses and housing, data from the BAG (Dutch: Basis Administratie Gebouwen, see https://bagviewer.kadaster.nl/) is used. This is data from municipalities which is up-to-date and freely available. For infrastructure, use was made of the NWB (Dutch: Nationaal Wegenbestand, see www.nationaalwegenbestand.nl), which is a database that shows the infrastructure network, including relevant attributes for both roads and railroads. The remaining land use information comes from the CBS (Dutch Central Bureau for Statistics, see www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/bestand-bodemgebruik) land use map. Use was made of two SSM2017 modules: Regional (for areas protected by regional flood defences) and Unprotected (for areas not protected by flood defences; Dutch: buitendijks). Damage functions describe the relation between the flood water depth and the damage. Each damage category has its own damage function. Damage functions in the module Unprotected are also different than for the Regional module, based on the assumption that buildings and people in unprotected areas are better adapted to and prepared for floods (Slager et al., 2013).

Using the derived flood depth maps in SSM2017, the total physical damage in the area flooded is estimated at around € 300 million – € 375 million (ENW, 2021), with most damage occurring in the ‘urban cores’ in the Geul valley. Physical damage elsewhere (for example buildings at the bottom of sloping areas) is estimated at € 25-75 million.

Economic losses occur when businesses are temporarily unable to operate (fully) after a flood. That business may be a shop, office or catering business which is closed temporarily until the building and fixtures and fittings have been repaired. These consequences can arise within and outside the flooded area. Here, we focus on the losses within the flooded area. Economic losses mainly occurred along the Geul; notably in Valkenburg where a lot of hospitality businesses and shops were affected. In addition to economic losses and physical damage to furniture and buildings, there also was a certain degree of local social disruption because of the short-term loss of critical infrastructure. There was a power outage that lasted for several days in Valkenburg, for example. Overall, additional losses due to electricity outages or transport losses (e.g., due to the failure of roads or bridges) or any cascade effect (dependent services) were limited due to relatively short disruption times (Koks et al., 2022).

The road and railway operators reported some 25 incidents, with inundated road segments and exits for one or two days. Electricity outages were reported for 1000 – 2000 households, where small and medium voltage stations were temporarily switched off by the electricity provider . Within a few days, power had been provisionally restored nearly everywhere. 100 – 200 households had no gas supply . Some 7000 households faced disruption of ‘wired’ ICT-telecom services, mostly due to flooding of infrastructure in the vicinity of flooded houses, but also due to power failures . Although five masts for wireless telecommunication were affected, enough redundancy remained to keep providing mobile services. (Koks et al., 2022)

A quote from an entrepreneur from Valkenburg illustrates the loss: *“Equipment that had previously taken 10 men to carry inside was on the other side of the shop. All the fixtures and fittings had to be taken out and are now out. And now everything must dry up… It is wishful thinking that I will be open again in mid-September – realistically, it’s more likely to be 1 October. The season will be over by then. It seems that we are insured for the fixtures and fittings but not for business interruption. And that is a major monthly expense too, with all the staff and rent. And we have already had the coronavirus. So once again, we will have to start again.”*

The estimated number of businesses affected is around 600 in total, approximately 25% of which were located along the Meuse and approximately 70% along the Geul. There is a lot of uncertainty regarding the estimated operating losses which lie between € 15 million and € 135 million. These estimates are based on the losses per business as presented by Thieken et al. (2016). In that study, a large-scale survey was conducted after various somehow comparable floods in Germany in 2013 on losses experienced by businesses. The low estimate is based on the median economic losses reported (€ 15,000) and the high estimate is based on the average reported losses (€ 137,287) from Thieken et al. (2016). The choice of the median and average losses is based on a discussion within the team of authors and is a subjective choice, based on the high variation in damages and the number of affected businesses in de flooded area. This wide range reflects the uncertainties with respect to the duration of recovery for various businesses, their specific income and the extent to which the various businesses were affected. In figure 4, the total estimates are shown in the form of a pie chart. The overall estimate of the flood (physical damage and losses) amounts to 350-600 million Euro. The uncertainty range comes from a sensitivity analysis in the flood damage model, and also because of uncertainties in damage estimates in the literature, see Thieken et al (2016).

The estimates of the different sectors are based on the number of objects (houses, businesses), the land use in hectares (crops, recreation, infrastructure and other), and the damages per object or hectare.

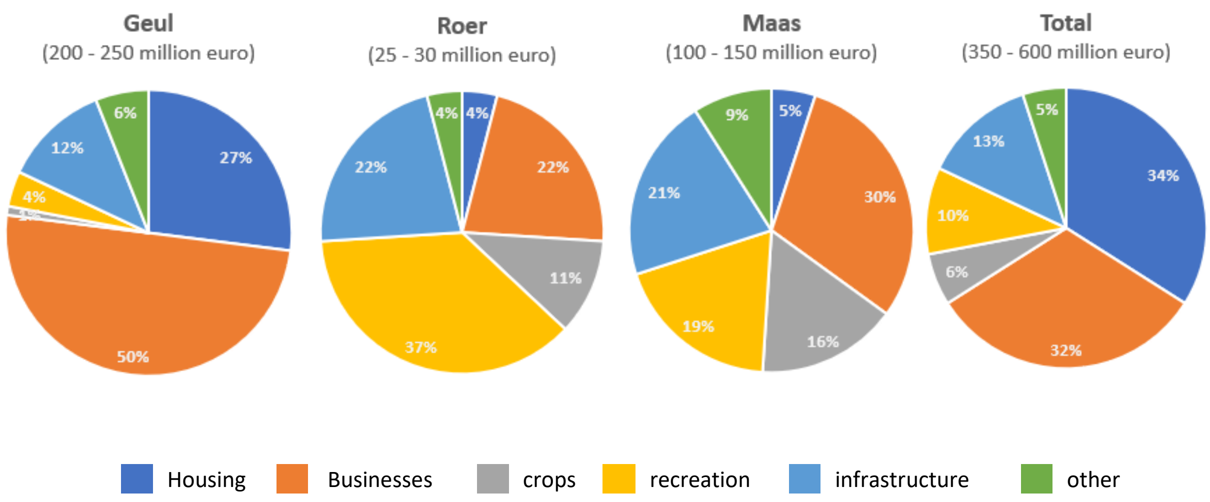

Figure 4: Initial estimates of physical damage plus damage due to economic losses for the various areas. In the total image, an estimate of damage to homes at the bottom of sloping areas throughout Limburg and damage along the Geleenbeek is added with a range.

4 Impact of new damage data (2 years later)

It can be questioned how reliable our initial damage assessment was, given that we did not incorporate assessments of damage experts on the ground. One and a half years later, these assessments have become available. It appears that our initial assessment is well in line with the reported compensation by insurance companies and governments, 2 years after the flood event. Table 3 shows the assessment of the Dutch government based on a variety of sources, resulting in a total damage of about 455 million Euro (we estimated 350 – 600 million Euro). Note that most values represent the values as assessed by damage experts, as usual in insurance industry. Damages as experienced by inhabitants, entrepreneurs and institutions may be larger than this. This may be explained by the fact that compensation usually reflects depreciated values, whereas higher replacement costs of new goods are incurred by the victims. Also, price effects (e.g., due to shortage of labor and material) and physical processes (e.g., mold developing in wet walls when renovation takes too long) can result in higher costs than initially estimated and compensated. Moreover, some cost categories are often not covered by insurance (such as business interruption). For some large entrepreneurs it is uncertain if insurance will pay out at all (often in cases of international stock insurances). Note that the authors of the report Kok et al, 2023 estimated also subjectively the not assessed damage by damage experts: in the last row of the table we can see that this contribution is relatively large (60 million euro out of 455 million euro, about 15%). For example: there was evidence that there is also damage which was not compensated by insurance companies.

Table 3: Overview of damage estimates of the 2021 flood in the Netherlands from a variety of sources 2 years after the event. The first category was collected by the Dutch association of insurers from the associated insurance companies. Other sources are RVO - the organization responsible for damage compensation payed by the Dutch government, and Water authorities / Ministry of Infrastructure and Water Management / Prorail.
Source of the table: Kok et al, 2023. A detailed comparison with the numbers in figure 4 is not possible, since insurance companies did not want to share detailed data.

	Category	Damage (million EUR)	Source of the data
1	Insured damage (homes and companies; objects)	224	Dutch association of insurers
2	National Act "Compensation of damage due to disasters" (WTS)	104	RVO
3	Law safety regions (WVR)	6	RVO
4	Additional measures municipalities	0	RVO
5	Business interruption	14	RVO
6	Crops	3	RVO
7	Infrastructure	17 26 1	Water authorities Ministry of Infrastructure and Water Management Prorail
8	Not estimated by experts (including stock insurance)	60	
Total		**455**	

5 Concluding remarks

We estimate that more than 2500 homes, 5000 residents and around 600 businesses were directly affected by the July-2021 floods in The Netherlands. Using the standard method for determining damage (SSM2017), experience and based on international sources, we initially estimated the total damage at € 350-600 million. This is in line with an updated estimate of € 455 million developed 2 years after the event. The range may also include items not yet identified. The main types of damage are property and structural damage to homes and businesses, economic losses and damage to infrastructure and agriculture. The damage caused by the flood to different homes and to different businesses varies greatly.

The damage for the total area flooded clearly exceeds the damage which occurred in 1993 and 1995 (€ 200 million and € 125 million in 2021 price level respectively, excl. damage due to economic losses); on the understanding that in the case of the 2021 floods, most of the damage was caused not along the Meuse but rather along the Geul and other tributaries of the Meuse . Our preliminary estimate is well in line with the knowledge 2 years later based on information from insurers, the WTS (Act on Compensation for Damages caused by Disasters) and some other institutions. This gives confidence in the rapid damage assessment approach used in this study and the national damage model (SSM2017) that underlies this assessment.

Even though the rapid damage assessments seem to yield a reasonable proxy of total damage, there is nevertheless a need to gather empirical data related to experienced damages and damage mitigation measures to find out more about flooding and damage experienced, repairs, effectiveness of risk reduction measures taken, evacuation and compensation. This has been done using a structured survey and results are reported in Endendijk et al. (2023a). Subsequent analysis of such empirical results can be used, inter alia, to validate and update the vulnerability curves, which form the core of the flood damage model used in this rapid damage assessment. In this context, it is worth mentioning that the empirical findings of Endendijk et al. (2023b) suggest that SSM2017 is (strongly) underestimating structural damage to buildings for water depths from 0 to 2 m. While this seems at odds with our finding that SSM2017 gives a fair proxy of total damage, it must be noted that structural building damage is only one of the many damage categories in SSM2017. A further study with more focus on such individual damage categories is therefore recommended.

Next to damage assessments as performed in this study, it is recommended to have a wide scope when it comes to impacts that floods can have on the people affected. For instance, consideration of how damage/compensation impacts the people affected. Compensation or damage assessments are often based on actual (depreciated) values, whereas people affected may suffer higher costs to replace their possessions. Doing assessments with replacement costs may better indicate how the impact is felt by the people. Next to this, indicators besides economic damage can be useful in determining the impact of a flood on people. For instance, the number of people not able to return to their homes within a month or three months may be a good indication of inconvenience experienced by affected people . Similarly, the recovery time of an area is important for inhabitants as there is a considerable difference whether normal practice is restored within weeks or months.

For decision makers, both economic and non-economic criteria can be important. This also opens the door to consider a wider variety of measures that can be taken. This is especially relevant for measures which do not require large investments (e.g. improving emergency protocols or warning systems, reducing the drying time of walls by applying layers on them) but may still soften the negative consequences of an extreme event for the people affected.

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Author contributions (CRediT)

MK[1]: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft. KS[2]: Formal analysis, Methodology, Software. HM[3]: Data curation, Methodology, Visualization., Software. WB[4]: writing -review and editing, Supervision. KB[5]: writing - review & editing. DW[6]: Investigation, writing – review and editing. SR[7]:Investigation. EK[8]:Investigation. KG[9]: writing - review & editing.

References

De Bruijn, J. A., Daniell, J. E., Pomonis, A., Gunasekera, R., Macabuag, J., de Ruiter, M. C., Koopman, S. J., Bloemendaal, N., de Moel, H., & Aerts, J. C. J. H., 2022. Using rapid damage observations for Bayesian updating of hurricane vulnerability functions: A case study of Hurricane Dorian using social media. International Journal of Disaster Risk Reduction, 72, 1-16. [102839]. https://doi.org/10.1016/j.ijdrr.2022.102839.

Dottori, F., Kalas, M., Salamon, P., Bianchi, A., Alfieri, L., and Feyen, L.: An operational procedure for rapid flood risk assessment in Europe, Nat. Hazards Earth Syst. Sci., 17, 1111–1126, https://doi.org/10.5194/nhess-17-1111-2017, 2017.

Endendijk, T., Botzen, W.J., De Moel, H., Aerts, J.C.J.H., Duijndam, S.J., Slager, K., Kok, M. and Kolen, B., 2023a (this issue). Experience from the 2021 floods in the Netherlands: household survey results on impacts and responses. Journal of Coastal and Riverine Flood Risk.

Endendijk, T., Botzen., W.J.W., de Moel, H., Aerts, J.C.J.H., Slager, K. and Kok, M., 2023b. Flood vulnerability models and household flood damage mitigation measures: an econometric analysis of survey data. Water Resources Research, 59, e2022WR034192. https://doi.org/10.1029/2022WR034192.

ENW, 2021. Hoogwater 2021 - Feiten en Duiding. Expertise Netwerk Waterveiligheid. https://www.enwinfo.nl/publicaties/

FEMA, 2021. FEMA Preliminary Damage Assessment Guide. Federal Emergency Management Agency, U.S. Department of Homeland Security. https://www.fema.gov/disaster/how-declared/preliminary-damage-assessments/guide

Gunasekera, R., Daniell, J., Pomonis, A., Donoso Arias, R.A., Ishizawa, O., Stone, H., 2018. Methodology Note on the Global Rapid post-disaster Damage Estimation (GRADE) approach. Global Facility for Disaster Reduction and Recovery, Washington, D.C., USA. https://www.gfdrr.org/en/publication/methodology-note-global-rapid-post-disaster-damage-estimation-grade-approach

Jiménez-Jiménez, S.I., Ojeda-Bustamante, W., Ontiveros-Capurata, R.E., de Jesús Marcial-Pablo, M., 2020. Rapid urban flood damage assessment using high resolution remote sensing data and an object-based approach, Geomatics, Natural Hazards and Risk, 11:1, 906-927, https://doi.org/10.1080/19475705.2020.1760360.

Kok, M., H.J. Huizinga, A.C.W.M. Vrouwenvelder en W.E.W. van den Braak, 2005. Standaardmethode2005 Schade en Slachtoffers als gevolg van overstromingen. HKV Lijn in Water en TNO Bouw PR999.10.

Kok, Matthijs, Don de Bake, Ron Bruijns, 2023. Actualisatie inschatting schade Limburg 2021. Overstromingen Maas, Geul, Roer en Geleenbeek. HKV, PR4774, mei 2023.

Koks, E.E., van Ginkel, K.C.H., van Marle, M.J.E., Lemnitzer, A., 2022. Brief communication: Critical infrastructure impacts of the 2021 mid-July western European flood event. Nat. Hazards Earth Syst. Sci. 22, 3831–3838. https://doi.org/10.5194/nhess-22-3831-2022.

LIWO, 2022. https://basisinformatie-overstromingen.nl/liwo/#/.

RVO, 2021. Quick Scanrapport overstromings-en regenvalschade in Limburg en het onbedijkte deel langs de Maas in Noord-Brabant juli 2021.

Slager, K., K.M. de Bruijn, A. Burzel, L. Bouwer en D. Wagenaar (2013). Verbeteringen gevolgenbepaling van overstromingen in buitendijkse gebieden Rijnmond-Drechtsteden. Deltares. 1208261-000-VEB-0004.

Slager, K, 2016. Technische documentatie SSM2017: Functionele en technische ontwerpkeuzen. Deltares. 1230095-004.

Slager, K. en Wagenaar, D., 2017. Standaardmethode 2017. Schade en slachtoffers als gevolg van overstromingen. Deltares. 11200580-004.

Strijker, B., Asselman, N., de Jong, J., Barneveld, H., 2023 (this issue). The 2021 floods in the Netherlands from a river engineering perspective. Journal of Coastal and Riverine Flood Risk.

Tay, C.W.J., Yun, SH., Chin, S.T. et al., 2020. Rapid flood and damage mapping using synthetic aperture radar in response to Typhoon Hagibis, Japan. Sci Data 7, 100. https://doi.org/10.1038/s41597-020-0443-5.

Thieken, A. H., Müller, M., Kreibich, H., & Merz, B., 2005. Flood damage and influencing factors: New insights from the August 2002 flood in Germany. Water Resources Research, 41, W12430. https://doi.org/10.1029/2005WR004177.

USACE, 2006. Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System, Draft Final Report of the Interagency Performance Evaluation Task Force, Volume VII – The Consequences

WB, 2011. 2011 Pakistan Floods – Preliminary damage and needs assessment. Washington, D.C., World Bank Group and ADB. http://documents.worldbank.org/curated/en/655781468058769881/2011-Pakistan-floods-preliminary-damage-and-needs-assessment

Wind, H. G., Nierop, T. M., de Blois, C. J., and de Kok, J. L., 1999. Analysis of flood damages from the 1993 and 1995 Meuse floods, Water Resour. Res., 35, 3459–3466, 1999.

Wts, 2021. Wet tegemoetkoming schade bij rampen. wetten.nl - Regeling - Wet tegemoetkoming schade bij rampen - BWBR0009637 (overheid.nl).9999