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Performance of flood defences in the Netherlands during the 2021 Summer floods

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Abstract

During the July 2021 Flood, the main flood defences along the River Meuse in the Netherlands performed well and did not breach. This paper is meant to document the various incidents on the flood defence system. As such, it provides an overview and description of the reported incidents related to flood defences, including a few breaches in minor flood defences. The incidents include overflow of embankments, sand boils, internal erosion at structures, and damage to a large weir and an outflow structure. Also, two local flood defences breached: an emergency embankment at Horn and an embankment in Roermond. During the event, the media reported on a dike breach at Meerssen/Bunde, however, after further investigation, it appeared that the concentrated outflow there was fuelled from a forgotten buried culvert.

Keywords

Flood defences, Levees, Failures, Emergency response, Field cases.

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1 Introduction

In July 2021, parts of Europe were hit by extreme rainfall, which led to significant flooding in the Meuse and Rhine river catchments (Cornwall, 2021). In the Netherlands, this ‘Summer flood’ was a rather unforeseen event as flooding typically occurs in the winter season (Slomp, 2021). The main affected region in the Netherlands was the southernmost province of Limburg, as the flood event attenuated when traveling further downstream. Figure 1 gives an overview of the study area. Unlike in Germany and Belgium, there were no casualties in the Netherlands. Yet, there was significant material damage, in particular in some of the Meuse tributaries such as the river Geul (Strijker & Kok, 2022). Following this flood event, various studies have been conducted to report how this event occurred, often on a country-by-country basis (Schaefer et al., 2021; Thieken et al., 2022; Koks et al., 2022; Zeimetz et al., 2021; ENW, 2021). Slomp (2021) provided an early estimation of the probability of the event and the uncertainties regarding design flood levels in the province of Limburg.

This paper describes part of the Dutch fact-finding study (ENW, 2021), focusing on the performance of flood defences and some other hydraulic structures during the 2021 floods along the Meuse and some of its tributaries within the Netherlands. Here, the term ‘flood defences’ refers to any method that is deemed to hold back floodwater such as dikes, barrages, locks, retaining walls, stop logs and sandbags. Post-disaster reports describing incidents or failures of flood defences can reveal unexpected failure mechanisms or help to improve emergency response (Sills et al., 2008).

During the events in July, the flood defences were subjected to an extraordinarily high water load; in some places, the water level that occurred was actually the highest ever. Therefore, additional measures such as the placement of sandbags were implemented on a large scale. All the locations where additional protection measures were implemented on the flood defences are indicated on the map in Figure 1 and differentiated based on the main reason for those measures. This map also shows that in many locations, the flood defences present worked well without the need for additional measures. However, incidents such as sand boiling behind a dike and problems with engineering structures did occur in a number of locations.

The overview clearly shows that in many locations where measures had been implemented, no failure occurred. This is partly because the actual maximum discharge was slightly smaller than in the scenarios which were taken into account at the time when those measures were decided upon. The near absence of wind during the peak of the flood surge also played a favourable role and as a result of this, there was hardly any wave runup or wave action. There are also many flood defences where no measures had been taken because according to (justified) expectations, they would be able to withstand the flood water. In the Netherlands, dike safety standards are defined for *primary flood defences*, which protect against floods from the major rivers, sea, and lakes, and for *regional flood defences*, which protect against floods from smaller rivers and canals. No dike breaches occurred in primary or regional flood defences along the Meuse. However, a breach did occur in a local (non-regional) dike near Roermond, resulting in flooding. In addition, an emergency dike made by residents in Horn failed.

The reports are based on field visits made by the research team and additional information from Limburg Water Authority, the Directorate-General for Public Works and Water Management (Rijkswaterstaat), the Flood Defence Emergency Team of Dutch water authorities and Rijkswaterstaat (CTW), media, and other open sources of information. The main part of this article consists of the ten incidents described in Section 2, varying from lack of height and geotechnical issues to erosion and miscellaneous issues. In Section 3, some concluding remarks are made.

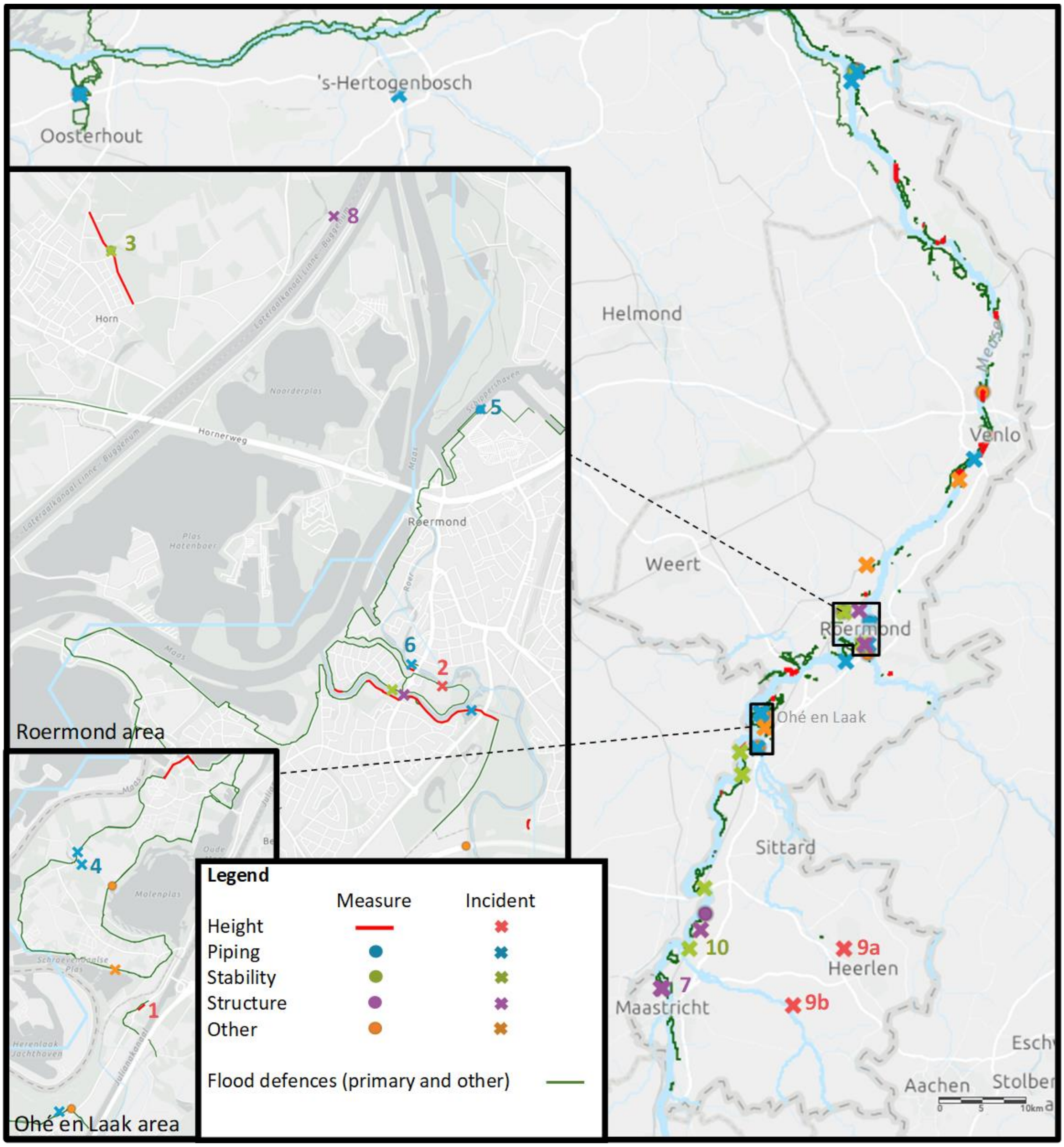


Figure 1: Map of the study area, indicating the locations where action was taken on account of the floods. The numbers refer to the paragraphs in section 2 with additional descriptions relating to the flood defences. Note: The installation of temporary stop logs, closing of cut-offs and similar measures were not included in this overview because they form part of the flood defence (they are only absent at low water). In addition, not all of the emergency measures taken by residents are shown on the map because that information is not available.

2 Overview of flood defence performance

2.1 Lack of height – example Aasterberg

As stated in the introduction, the flood defences were generally high enough for the water levels that occurred. However, at a few locations the water level was very close to the crest level. This can be seen in Figure 2 in which the crest level and the water level are compared for the dike sections along the Meuse between the Belgian-Dutch border (kilometre 0) and the village of Gennep (kilometre 155). Each point represents a dike section and the most critical point of each dike ring area is shown with a bigger marker and its code number. It should also be noted that there may be small differences between this figure and the situation in the field during the flood, because of both changes that occurred since the survey for AHN3 (the third version of the nationwide digital elevation model of the Netherlands), and local differences between the hydrological model and reality, resulting from e.g. the model grid size and local backwater effects.

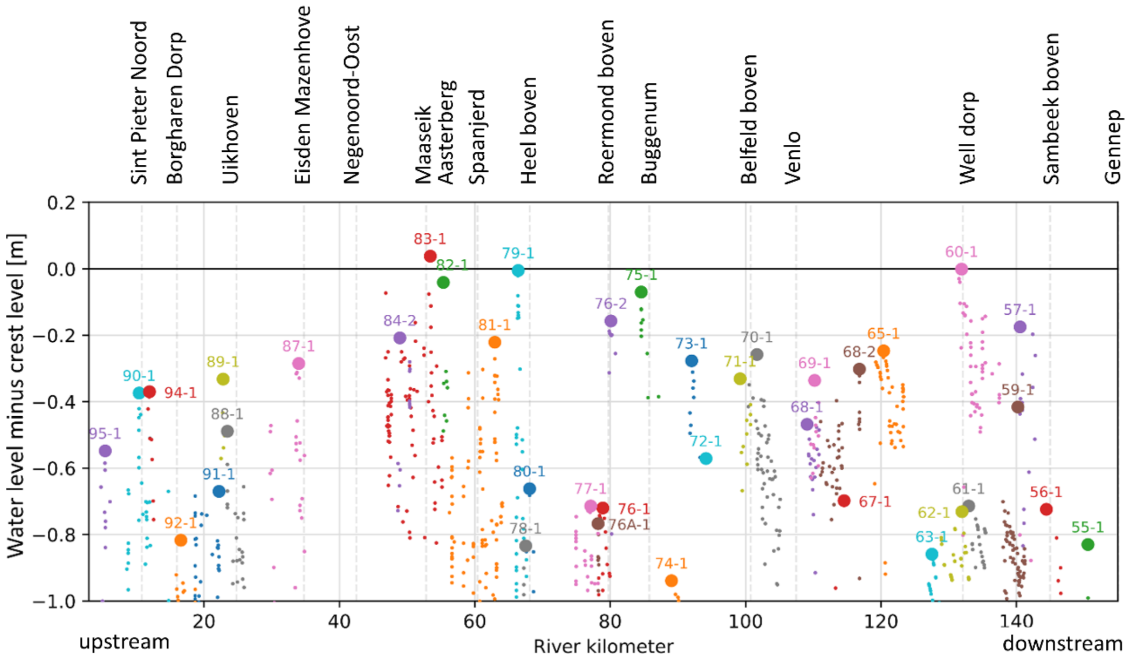


Figure 2: Differences between crest level derived from elevation model AHN3 and modelled water levels for all dike sections along the Meuse between the Belgian-Dutch border and Gennep (figure courtesy of Jurjen de Jong, Deltares).

An example of this is the dike section 82, locally known as Aasterberg (Figure 3). During the peak of the floods along the Meuse, locally on Friday 16 July, the water level near to the northern side of this small dike section rose higher than the crest of the dike (contrary to what the previous figure suggests). Sandbags had been installed in time on the raised road behind the dike which prevented the area from flooding. The residents were evacuated (1Limburg, 2021a). At the critical sections indicated in Figure 2, most notably dike section 83, sand bags were applied as an effective measure.

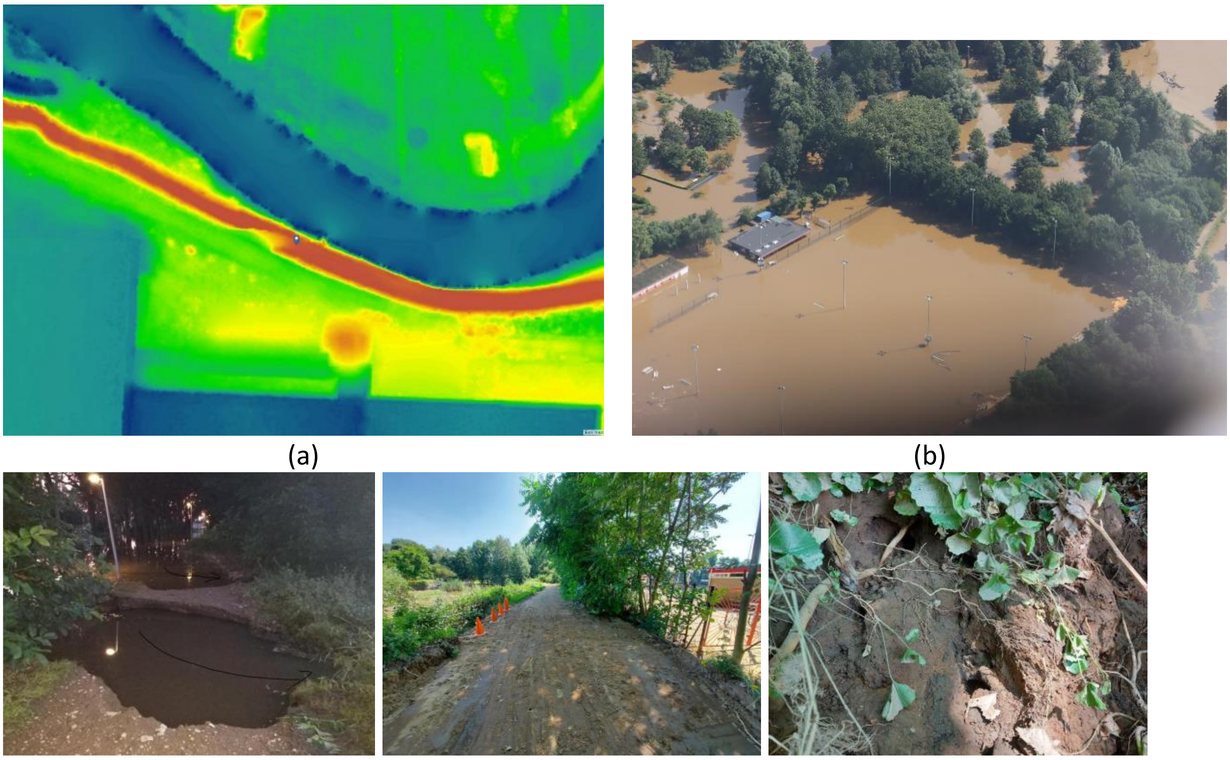
Figure 3: Aerial view of Aasterberg (upper left corner) on July 16, 2021, a few hours before peak flood level (photograph Dutch Coast Guard).

2.2 Breach near Concordia hockey fields (Roermond)

One of the few locations where a complete breach occurred in a levee, is a location near the hockey fields of Roermond Hockey Club Concordia. This breach is located between the Roer and the Hambeek, two tributaries of the Meuse River in the Roer delta, to the east of the street called Bisschop Lindanussingel. This is an uninhabited diked area, and the dike has no formal safety classification set by law like the primary and regional flood defences.

A breach approximately 2 m wide occurred in the dike after an overflow of a slightly lower part of the crest (Figure 4). At this location, the crest height is NAP + 21.10 to + 21.20 m while the maximum water level was NAP + 21.43 m, as indicated by measurements at station “Roermond Andersonweg bij stuw Hoge Bat” [https://www.waterstandlimburg.nl/Home/Waterstanden/140]. High-water marks on the nearby floodgate to the west of the Bisschop Lindanussingel indicate a similar level, which must have been the same at the breach location, because there was hardly any current in this branch of the Roer as the downstream floodgate was closed (see Section 2.6). Due to the flooding, the hockey fields were almost 2 metres underwater. Based on several sources of information, the following timeline of events can be reconstructed:

- 17 July shortly after midnight, the water level reached the dike crest level [Waterstandlimburg.nl]
- 17 July at 01:16 AM, a video of the flooded hockey fields was shared on Facebook (Facebook, 2021)
- 17 July at around 10:00 AM, the water level reached the maximum level [Waterstandlimburg.nl]
- 17 July at 11:15 AM: aerial photo (Figure 4b)
- 18 July 22:10 PM: photo of outflowing water through the breach (Figure 4c).



(a) (b)

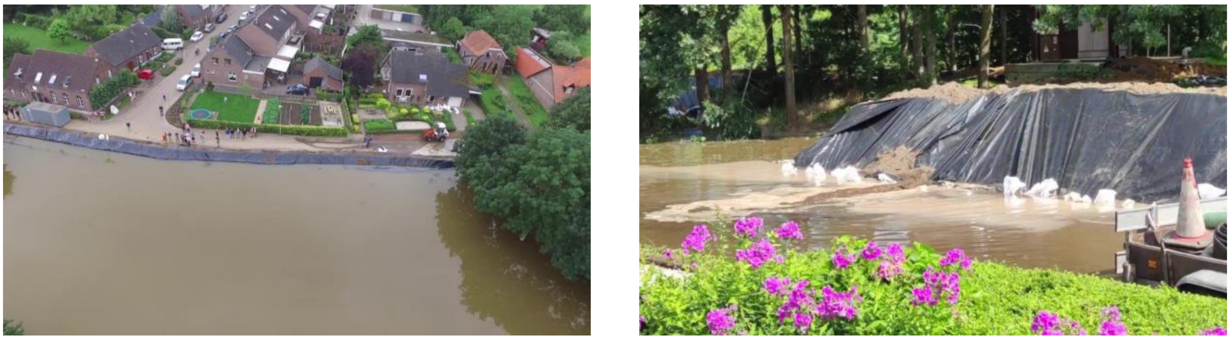
(c) (d) (e)

Figure 4: Concordia hockey fields: (a) digital terrain model showing locally lowered crest at the first breach location, situation before the floods (from the nationwide elevation model AHN3), (b) aerial photograph taken on Saturday 17 July at 11:15 AM – the dike with breach is located just behind the clubhouse and the blue container among the trees (photograph Dutch Coast Guard), (c) situation with backflows with the scoured location of the lower crest at the front and the breach location behind (photograph David Knops, HKV), (d) sealed breach, : holes in dike embankment approximately 100 m from the location of the breach.

It is not known when exactly the breach occurred, whether this was before the water entered the area or after. Therefore, the failure mechanism at this location cannot be inferred clearly from the observations. As the maximum water level in the Roer exceeded the local depression in crest level, external erosion by overflowing water is a likely candidate. Traces of external erosion at the inner slope have been observed on the same levee, about 100-200 m from the breach location. It is also possible that burrowing by animals played a role in the weakening of the levee and the occurrence of the breach: holes several centimetres in diameter were found in a number of places in the dike embankment near the breach location, possibly made by voles (Figure 4e). These holes increase the vulnerability for saturation and slope instability and internal erosion from the embankment body. However, if the breach occurred after the area flooded due to overflow, a possible failure mechanism is that the breach was caused by the outflowing water, for instance external erosion or slope instability of the outward slope (by then, the river level was lower and the levee must have been saturated).

2.3 Breach of emergency dike near Horn

The village of Horn near Roermond is located on the boundary of a flood retention area called Lateraalkanaal-West. The lowest street in the village runs adjacent to the retention area. There is a flood defence here (without an official primary or regional status) consisting of a low retaining wall on which concrete blocks can be stacked if necessary. Those blocks were not used during the most recent floods. According to residents, the contractor who should do this in case of flooding was bankrupt. Therefore, residents built an emergency dike approximately 450 m long, shortly before the flood came. It consisted of a loose earthen embankment covered with an impermeable plastic sheet (Figure 5a). In the afternoon on Saturday 17 July at around 13:00, this dike breached (Figure 5b). At that moment, the water level was well below the crest. Two possible causes are: softening by seepage water inside the dike or erosion due to a leak in the geotextile. There was a lot of seepage water behind the dike, including flow from a manhole which was probably in contact with the water in the retention area. This could have caused softening of the newly applied soil.



(a) (b)

Figure 5: (a) Emergency dike near Horn with the location of the subsequent breach to the right (YouTube, 2021a), (b) the start of the breach (YouTube, 2021b).

2.4 Sand boil at Sint Annakapel

One important failure mechanism for dikes is backward erosion piping (underseepage). A difference in water level across the dike results in sand being washed out – a so-called sand boil. Several sand boils developed near the flood defences along the Meuse. In most cases, these were found during the floods. Depending on the severity of the erosion or seepage, the water level difference was reduced using a ring of sandbags. Hence, the driving force behind the erosion was reduced.

A sand boil at St. Annakapel near the village of Ohé en Laak, was not discovered until the water had subsided (Figure 6a). This sand crater measuring 120 cm in diameter was located approximately 100 m from the landside dike toe, in an area that had become low-lying on account of gravel extraction carried out in the past, see Figure 6b. The maximum water level difference across the dike here was approximately 4 m. The combination of a low-lying, highly permeable subsoil, and the presence of an old channel belt under the dike makes this location particularly vulnerable to the development of seepage and possibly backward erosion piping. Further investigation of the local subsoil is required to reveal where the sand came from and whether additional reinforcement measures to protect against piping are required.

(a) (b)

Figure 6: (a) Remnants of a sand boil near St. Annakapel observed after the floods. The sand deposited is relatively fine. (b) ground level in the area of the sand boil (based on the nationwide elevation model AHN3), the dikes are indicated by means of a green line.

2.5 Internal erosion at hydraulic structure: Designer Outlet Roermond

On Friday 16 July, an industrial zone in Roermond – where businesses including a large Designer Outlet are located – was evacuated. According to the water authority, the area was evacuated because of the risk that the retaining walls were not high enough. During an inspection by members of the Flood Defence Emergency Team (CTW) on Saturday 17 July, active internal erosion was found between two retaining walls in the dike section along Schippershaven, see Figure 7.

It was observed that the outflowing water was turbid and that there was sand around the boil. The CTW advised building a ring of sandbags around the boil in order to stop the flow of water. Implementation of the measures was stopped shortly after starting because the local situation was deemed too dangerous for the people carrying out the repairs. After the flood event, it was inferred that the newer retaining wall was not attached correctly to the older retaining wall and the water was able to get in through the small gap between these walls. No water marks were observed on buildings and walls in the surrounding area, suggesting that the area remained dry and the water drained away via the sewers.

(a) (b)

Figure 7: Signs of internal erosion at the junction between two different retaining walls: (a) overview showing the lower and higher retaining walls, (b) detail showing the hole left behind (the red and white blocks on the card each measure 10 by 10 cm).

2.6 Internal erosion at hydraulic structure: Roer floodgate

Another incident with internal erosion occurred at a floodgate in the city of Roermond (Figure 8). This floodgate in the Roer river, which is a tributary of the Meuse river, was closed in order to protect the city centre from flooding. At this location, excessive seepage and erosion in the corner of the L-shaped wall on the downstream side was reported on Saturday 17 July at 03:15 AM. The sand boil was bringing up coarse sand and gravel. Half an hour later, the first ring of sandbags was put down (see Figure 9ab) which was eventually built 3 to 4 layers high (Figure 9c). This stopped the erosion process. In the afternoon, again outflow of water and sand was reported, and the ring of sandbags was heightened to a height of 60 to 80 cm which turned out to be sufficient to stop the erosion for the maximum water level drop of more than 1.6 m that was present over the structure. To be sure to stop further erosion, the area near the corner was completely filled with sandbags [Figure 9c].

After the floods, a poor connection was found between the sheet pile and concrete cover on the high-water side (Figure 9d). This opening may have enabled the water to flow through the opening, and down behind the sheet pile, resulting in the formation of the sand boil.

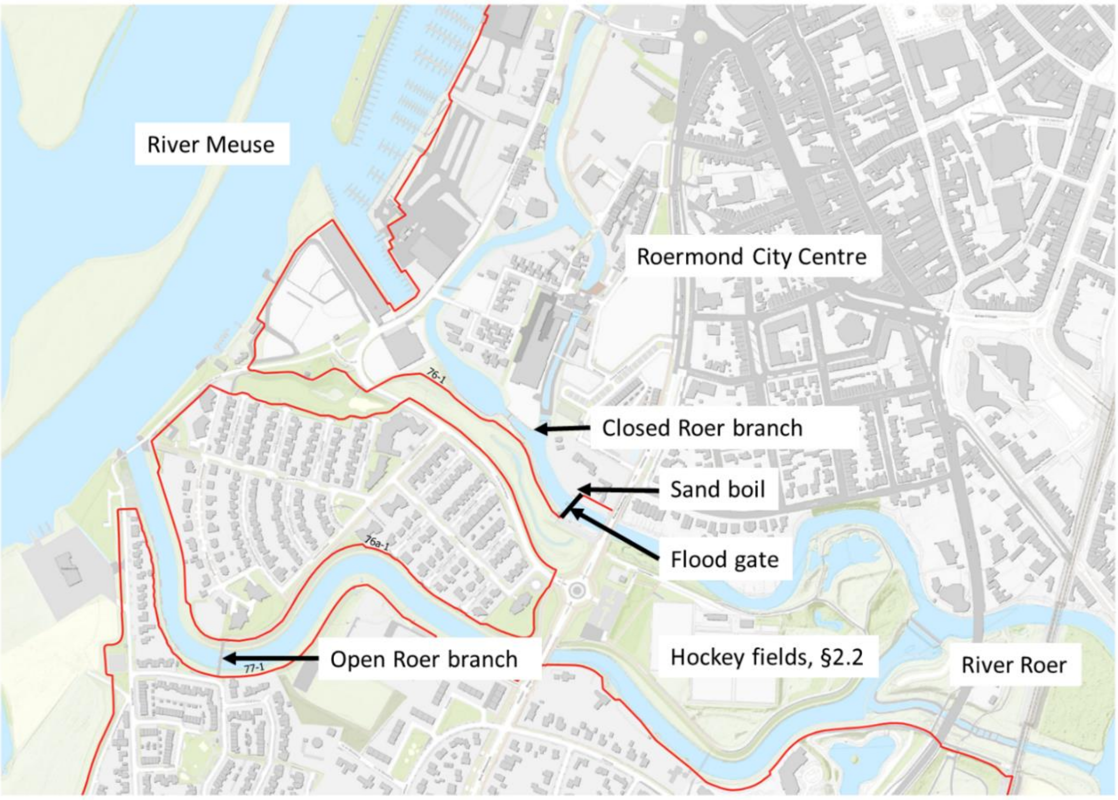


Figure 8: Overview of the area around the Roer flood gate in Roermond.

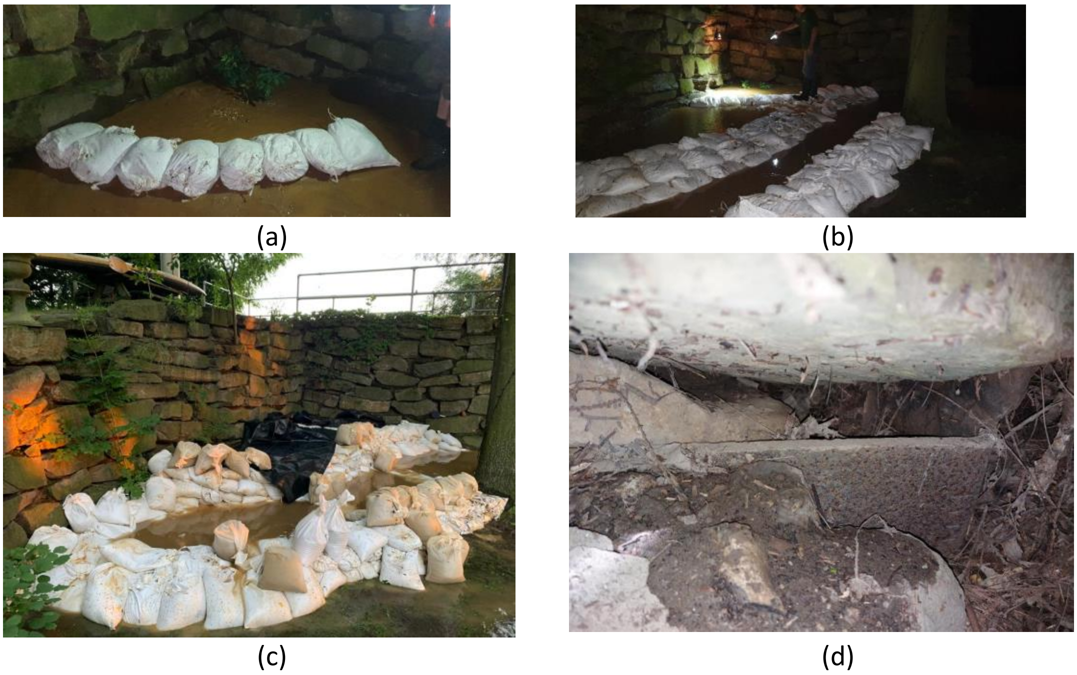


Figure 9: Observations around the Roer floodgate: (a) sand and gravel deposited near the first sandbags (photograph Guido van Rinsum, Witteveen+Bos), (b) ring of sandbags on 17 July at 04:30 (photograph Guido van Rinsum, Witteveen+Bos), (c) sandbags on 17 July at around 20:00 (photograph Guido van Rinsum, Witteveen+Bos), (d) the poor connection of the gate structure between sheet pile and concrete cover on the high-water side, photo taken after the flood.

2.7 Barrage near Bosscherveld (Maastricht)

The Borgharen barrage is located directly downstream of the Julian Canal's entrance in the Meuse floodplain, between Maastricht and Borgharen. The Bosscherveld bypass which incorporates a fixed barrage runs parallel to this. That barrage consists of an earth dam with stone revetment on the downstream side. On top of the dam, there is a steel edge approximately 15 cm high, consisting of anchored elements which are each 4 m long. When the water level dropped, it was found that one of these steel elements that was located roughly in the middle of the dam had disappeared. Behind was an erosion hole approximately 15 m wide and up to around 1.5 m deep. This became visible during the afternoon of Saturday 17 July, when the discharge via the barrage was already significantly reduced. It was decided to carry out an acute emergency repair for which the army was also deployed (1Limburg, 2021c) on account of the poor accessibility of the location with equipment, see Figure 10.

Despite not being a critical situation, partly because a dam-break flow would remain within the Meuse river, it was decided to carry out the immediate repairs on account of further damage in case of a possible second flood event. For instance, a further widening of the erosion hole could cause the crest to collapse and further erode the earth dam in a lateral direction. The accessibility for repairs would get much more problematic in that case. At the same time, the water level at Borgharen would no longer be controllable by the barrage, which is important for the stability of structures in the Juliana Canal.

Incidentally, the abovementioned damage was at the same location as previous damage which occurred about ten years ago. The repairs probably created a weak spot. In addition, the detailing of the anchoring of the steel edge, with an easily removable locking pin, seems susceptible to vandalism.

Figure 10: Barrage near Bosscherveld: (a) emergency repairs with the assistance of the army (photograph Wilbur van Beijnen, Directorate-General for Public Works and Water Management), (b) overview of defence after repair (high-water marks still visible from the vegetation in the background), (c) detail of anchoring of steel edge.

2.8 Erosion at outlet structure Zeven Ellen Waterlaat near Horn

The Lateraalkanaal-West retention area near Horn (see also Section 2.3) includes an outlet structure for emptying the retention area after floods have passed. On the afternoon of Wednesday 21 July, damage to this outlet structure was reported. The site was also visited by the research team two days later, see Figure 11. The damage concerned erosion of the dike at the outlet structure. While the water should have flowed through the pipes directly into the river, a large part of the water came out through an inspection hole. The damage to the dike was caused by the flow of water from the broken southern pipe, as shown in Figure 11c. As the flood had receded, a dike breach was no longer possible, but the design of this outlet structure must be improved before it is repaired to prevent future similar damage.

Figure 11: Zeven Ellen Waterlaat near Horn: (a, b) situation on 21 July (photographs Erik Bijlsma, Directorate-General for Public Works and Water Management), (c, d): situation on 23 July with a level of approximately 1.95 m below the peak water level in the retention area.

2.9 Rainwater storage basins

In various places in South Limburg, rainwater storage basins have been created in order to protect the built-up areas against flooding and mudflows. One example of a storage basin is 'De Dem' near the village of Hoensbroek. The main purpose of this buffer is to store sewer overflows from the urban district of Heerlen. The first warning regarding an embankment of this basin was issued on 14 July at 15:12. The reason was that the basin was full but rainwater was still flowing in. The overflowing water led to erosion of the embankment, see Figure 12, but the embankment did not fail. It is recommended for such rainwater storage embankments to be provided with an erosion-resistant overflow structure with sufficient capacity so that failure cannot occur.

(a) (b)

Figure 12 De Dem water storage basin with (a) the outflow location in the bottom right-hand corner of the photograph and (b) traces of erosion in the same location (photographs provided by Bas Jonkman, TU Delft).

The ‘Ransdaal’ rainwater storage basin is located northeast of the village of Schin op Geul, see Figure 13. During the extreme rainfall event, floods occurred downstream of the area along the Scheumerbeek. For example, the nearby hotel downstream of the storage basin was flooded with several decimetres of water. During the field visit, it was found that water had overtopped the dike – in the middle and along the eastern side of the dam. The water flowed through a tunnel (where there were signs of significant erosion that point to high flow rates), and that led to the flooding downstream along the Scheumerbeek. This affected the hotel and a number of houses.

Figure 13: Location of Ransdaal storage basin near Schin op Geul (left) and images of the basin, the dike/embankment, and the erosion in the tunnel downstream (photographs provided by Bas Jonkman, TU Delft).

2.10 Situation near Meerssen/Bunde

On the afternoon of Friday 16 July, various media reported that a dike had breached near the village of Meerssen or Bunde (1Limburg, 2021b) - (RTL News, 2021) - (De Telegraaf, 2021). On closer inspection, it was found to be a substantial sediment-carrying flow of water which also washed out gravel, just to the north of the approach road leading to the bridge over the Juliana Canal near Bunde, see Figure 14 and Figure 15. As a matter of urgency, this water flow – that was mistaken for a large sand boil– was handled by installing a coffer dam more than a metre high consisting of around 3000 sandbags which stabilised the situation. It was initially thought that the dike along the Juliana Canal which is elevated here was on the verge of failing due to a leak from the canal or from the Meuse. However, it was water from the Geul that was the problem, see Figure 15. Because not all of it could flow through the culvert under the Juliana Canal, it flowed along the eastern side of the Juliana Canal to the north. At the approach roads leading to the bridges near Bunde and Geulle, water then flowed around the road and through the originally constructed culverts. However, near Bunde the culvert had become covered and was not included in asset databases so that the flow of water from this culvert was initially misinterpreted as coming from the subsoil (“sand boiling”). It was discovered that there was a culvert here a week later when further investigation of this location was carried out. This last example clearly shows how the capacity of emergency services can be absorbed to a significant extent by issues that appear to be irrelevant at hindsight – or with sufficiently reliable asset information on beforehand. Other examples of non-critical cases which consumed less resources are a tunnel near Roermond and a canal dike near Oosterhout (ENW, 2021).

Figure 14: Situation near Bunde: (a) prior to effective measures (photograph Bertram de Rooij, WUR/Fire Service Gelderland Midden), (b) stabilised boiling (photograph Hoite Detmar, the Directorate-General for Public Works and Water Management), (c) boiling area with dimensions after drying out, (d) the concrete culvert where the water came out (photograph Anton van der Meer, Deltares).

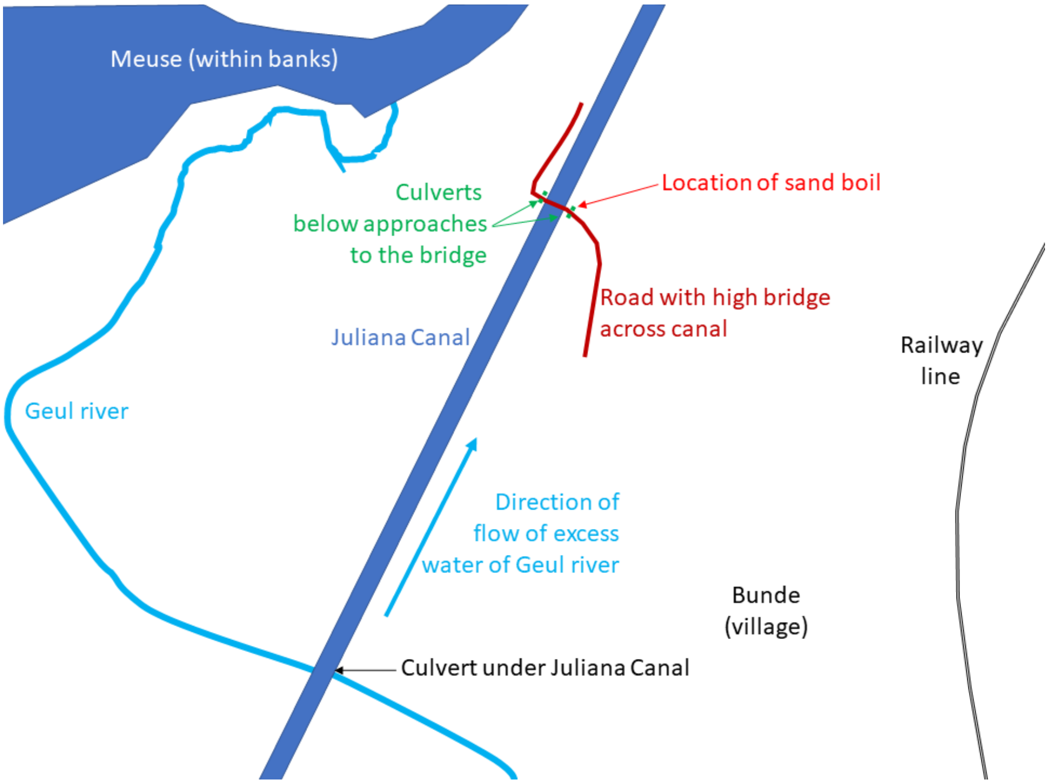


Figure 15: Situation plan around Bunde bridge.

3 Concluding remarks

An assessment of the performance of flood defences in the Netherlands during the 2021 Summer floods was undertaken. The maximum water level imposed on the primary and regional flood defences along the Meuse in The Netherlands during this flood event was very high, and in some locations, it just exceeded the crest level. Under this high load, the flood defence system generally worked well. This information can be included as a proven strength in the safety assessment of the defences. However, the relatively short duration of the floods must also be taken into account, as well as the emergency measures taken. A general comparison between the safety assessment of the flood defences and the incidents and height deficiencies that occurred also appears useful. Follow-up analyses are desirable for the piping failure mechanism in order to gain a better understanding of the sand boils in relatively coarse sand and gravel that occurred and to be able to clarify these using computational models, which may have to be improved for this purpose.

Two of the incidents relate to poor connections in ‘hard’ flood defences: the floodgate on the Roer and the retaining walls near the Designer Outlet, both in Roermond. These connections require extra attention during design, assessment, and inspection.

The incidents with the overflow of the rainwater retention basins near Hoensbroek stress the need for more robust designs which provide additional resistance in case of events slightly above the design conditions (e.g., an erosion-resistant overflow structure with sufficient capacity).

A general lesson that can be drawn from the events relates to the availability of reliable information on the physical infrastructure. It was extremely important to have up-to-date information on the state of the flood defences, supplemented with information from inspections, and field observations. During the floods, this information guided decisions regarding the locations where emergency measures were most necessary. Another example is the lack of information on the hidden culvert in Bunde, where more complete information could have prevented unnecessary flood fighting efforts and evacuations.

All of the above should be prepared and implemented during the ‘cold phase’ in order to further improve flood protection before the next flood strikes.

Acknowledgements

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Author contributions (CRediT)

AK[1]: Conceptualization, Investigation, Visualization, Writing – original draft. JP[2]: Conceptualization, Investigation, Visualization, Writing – original draft. MvS[3]: Investigation, Visualization, Writing – review & editing.

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