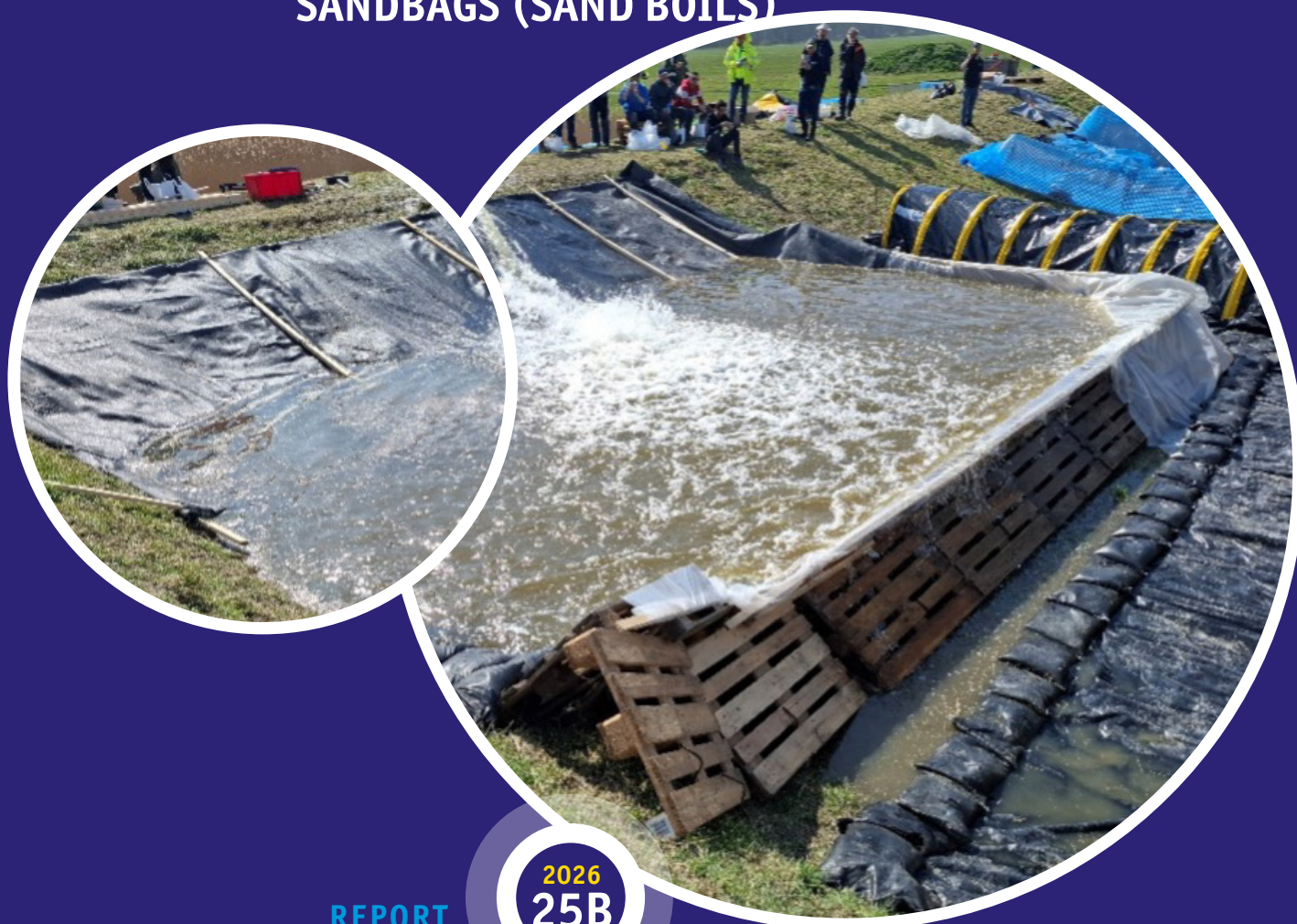


EVALUATION OF EMERGENCY FLOOD PROTECTION EXERCISE

AN EXERCISE IN THE MARNEWAARD WITH
MOBILE BARRIERS, EROSION PROTECTION AND
SANDBAGS (SAND BOILS)



REPORT

2026
25B

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PREFACE

PRACTICAL EXERCISE MAKES EMERGENCY MEASURES FOR FLOODING TANGIBLE AND DEPLOYABLE

This report shows which emergency measures for flood protection work in practice, where limitations exist, and what is needed to deploy them reliably during a crisis. It provides water authorities, crisis organizations, and knowledge partners with concrete lessons for preparation, training, work instructions, and the further development of mobile barriers, sheet piling, and sandbag measures.

Extreme weather and flood situations require emergency measures that can be applied quickly, safely, and under pressure. Within the Interreg North-West Europe BONSAI project, a practical exercise was therefore conducted on 14 and 15 April 2026 in the Marnewaard, testing various temporary measures for water safety. The societal relevance is high: water authorities, Rijkswaterstaat, Ministry of Defence, safety regions, and international partners must be able to rely in crisis situations on measures that are not only sound on paper, but also feasible in the field.

During the two-day practical exercise, mobile barriers including pallet barrier, erosion protection measures, and sandbag techniques were constructed and put to the test with water. All methods were evaluated, including the dismantling of the techniques. The exercise revealed clear differences in ease of use, construction speed, transportability, stability, susceptibility to leakage, and ease of removal. The Europallet system and Haawal proved to be particularly robust and practical for deployment. For the TubeBarrier and the Buitink Flexible Water Dam, points of attention emerged regarding handling, connections, underflow, emptying, and cleaning. For erosion protection measures, it became clear that standardization, clear work instructions, and strong visual support are crucial.

The main conclusion is that practicing under conditions as realistic as possible is indispensable. Only in practice does it become visible whether systems connect properly, how participants interpret instructions, and which safety and operational issues arise. The report recommends further improving work instructions, testing more variants and higher barriers, paying attention to connections between systems, and actively sharing the acquired knowledge via, among others, Wiki Emergency Measures. A follow-up question is how these lessons can be translated into widely applicable tools, training programs, and standard operating procedures for crisis organizations.

The research and the exercise were made possible in part through co-financing from Interreg North-West Europe and are part of the BONSAI project (NWE0400542). The exercise was carried out with the involvement of, among others, the Crisis Team Flood Defences, Defence, STOWA, Deltares, Dutch and Flemish water managers, and knowledge partners.

Mark van der Werf
Directeur STOWA

SUMMARY

On 14 and 15 April 2026, the Crisis Team for Flood Defences (CTW), within the framework of the Interreg North-West Europe BONSAI project, conducted a joint field exercise at the Defence training area in Marnewaard. The exercise focused on testing and evaluating emergency flood protection measures. During this two-day training event, various mobile flood defence systems (Haawal, TubeBarrier, the Buitink Flexible Water Dam and a Euro-pallet frame system), sheet-pile repair techniques, timber formwork methods and sandbag stacking techniques were installed under partly realistic conditions, partly tested under hydraulic loading, and subsequently dismantled.

The focus was on familiarising participants with the measures and assessing their practical applicability, ease of deployment, installation and dismantling speed, transportability, and behaviour under loading. The focus was not specifically on deploying the measures under severe operational conditions, as the weather conditions were too favourable. In addition, an important objective was to facilitate joint learning and training at a national level involving water authorities and Defence personnel.

Clear differences were observed between the systems in terms of installation and dismantling time, ease of use and performance. The pallet-based frame system performed surprisingly well and proved to be practically deployable. Not all systems and connections integrate effectively with one another, particularly when different types of mobile flood defence systems are connected.

The Euro-pallet frame system and the Haawal system performed robustly and proved practical in use, whereas the TubeBarrier and the Buitink Flexible Water Dam revealed several points requiring attention with respect to installation, transportability, removability, leakage susceptibility and connections to other systems.

For sheet-pile repairs, testing different implementation variants was considered highly valuable. At the same time, it became apparent that further standardisation and improvement of work instructions are required to enhance applicability during emergency situations.

In general, it was concluded that field exercises under realistic loading conditions are essential for assessing the effectiveness of emergency measures. The exercise highlighted the importance of:

- good preparation and coordination between the systems being tested;
- further development and knowledge sharing (including knowledge related to sheet-pile repairs);
- testing additional configurations, such as higher flood defences;
- clear instructions and qualified instructors.

The combination of different measures and systems within a single exercise resulted in a significant learning effect for the participants. The exercise provided valuable insights into the practical deployability of the tested systems. For many participants, the systems tested were unfamiliar. It also became evident that mobile flood defence systems can be applied in four different ways: on a flood defence structure, behind a flood defence structure (that may potentially fail), within a watercourse to retain water, and at ground level to divert water away from a critical asset.

ABOUT STOWA

KNOWLEDGE ABOUT WATER, FOR TODAY AND TOMORROW

The Foundation for Applied Water Research – STOWA – serves as a knowledge platform for Dutch regional water managers. From our office in Amersfoort, we develop and collect, disseminate and promote the use of knowledge in water matters. Water managers need this knowledge to properly carry out the tasks and challenges they face. STOWA provides knowledge on a broad range of topics, covering subjects such as urban & rural climate adaptation, water quality and ecology, sustainable and effective wastewater treatment, safe dikes, energy transition or circular economy.

The type of knowledge we provide may be technical and scientific in nature but can also relate to governance, administrative and/or legal matters. To ensure that this knowledge can be put to practical use by water managers, our research is mostly presented in the form of reports, practical guides, tools and instruments. We also facilitate learning communities for the purpose of sharing and anchoring knowledge and we organize symposia, work sessions and webinars.

To create as much impact as possible, STOWA pays particular attention to organisational and human factors that influence the impact of our output. We believe change is realized by people, through the application of knowledge. In our quest for solutions and innovation, we look beyond our own network, at different sectors, new perspectives and other countries.

STOWA works demand-driven but also puts issues on the agenda. We gather and compile knowledge questions from water managers and assign them to the right knowledge suppliers: universities, knowledge institutes or consultancy firms. We conduct tenders and offer guidance for knowledge projects. We ensure that water managers remain connected to the projects to sustain the practical application of project results. To this end, each project is supervised by a working committee in which regional water managers are represented. The broader terms of research are determined by programme committees whose members include water managers.

STOWA is independent, impartial and transparent. The users of our knowledge output must be able to fully rely on the integrity and quality of our findings. This guarantees that our knowledge serves as a reliable source for water management and innovations that respond to the challenges of today and tomorrow. However, it is up to water managers to determine how they apply STOWA's knowledge.

STOWA is a non-profit organization (RJ-640). In addition to numerical financial statements, our annual report includes a management report on the foundation and its activities. Our annual budget is about 20 million euros. Our participants collectively contribute about 10 million euros per annum as a structural contribution. Additionally, we receive around 10 million euros per annum through contributions to specific projects.

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1

INTRODUCTION

1.1 BACKGROUND

On 14 and 15 April 2026, the Crisis Team for Flood Defences (CTW), together with the Ministry of Defence and STOWA, conducted a training exercise at the Defence training facility in Marnewaard, Groningen, within the framework of the Interreg BONSAI project. The exercise was attended by more than 100 participants, with approximately 50 participants per day. Participants included representatives from Dutch regional water authorities, Rijkswaterstaat, STOWA, De Vlaamse Waterweg, the Flemish Department of Mobility and Public Works, Duisburg Fire Brigade, HZ University of Applied Sciences, Deltares, and the University of Siegen (Germany).

1.2 TRAINING SITE

The training site is located on a military base. Several years ago, a basin surrounded by an embankment was constructed on the site to facilitate a test in which the Ministry of Defence created a controlled breach in the embankment using explosives. This test was developed within the framework of the Interreg project P2C's through collaboration between the Ministry of Defence, STOWA and Dutch water authorities.

In 2025, a second exercise was conducted focusing on safe working practices in and around water, the detection of muskrat burrows, and the closure of these burrows using various emergency measures. The training exercise held on 14 and 15 April 2026 can therefore be regarded as *Marnewaard III*.

The figures below show the training site and the planned exercise locations, including the required positioning of materials.

Figure 1.1 Location of Marnewaard

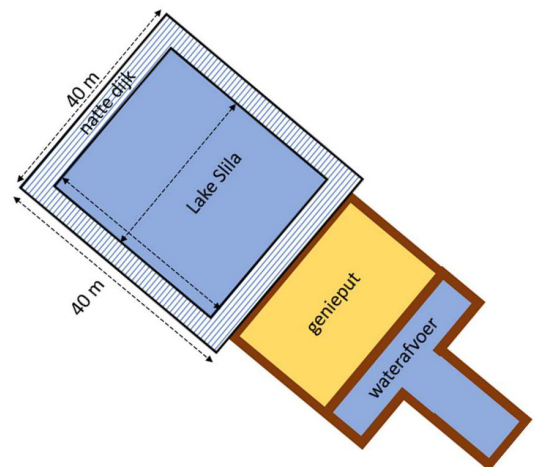
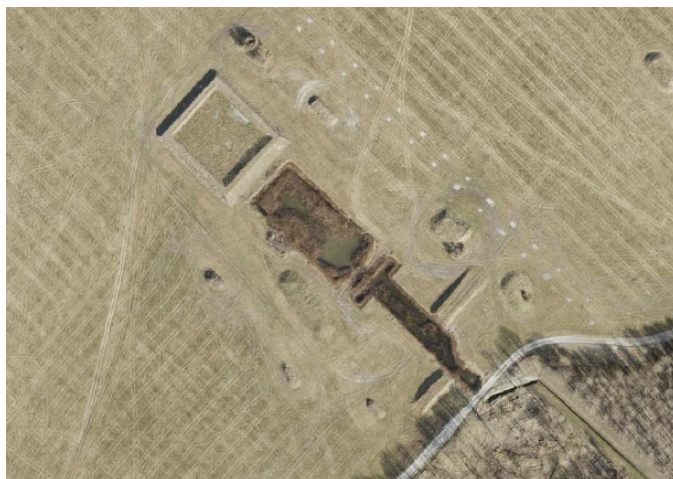


Figure 1.2 View of the training site



Figure 1.3 Planned positioning of materials



Figure 1.4 Overview of the planned locations for the installation of the different slope protection covering configurations



Figure 1.5 Pre-exercise briefing at a container adjacent to the training site



1.3 TRAINING OBJECTIVES FOR MOBILE FLOOD DEFENCE SYSTEMS

1.3.1 EURO-PALLET MOBILE FLOOD DEFENCE SYSTEM

The objective was to construct approximately 20 m of mobile flood defence on uneven ground, including at least one 90-degree bend and a reliable connection to an embankment slope with an inclination of approximately 1V:1H. The target retained water level was 1.2 m.

The concept of using wooden pallets was proposed, among others, by the Duisburg Fire Brigade, which considers this approach a promising emergency measure because wooden pallets are widely available in large quantities and can be rapidly sourced by emergency responders, businesses and members of the public.

Learning objectives

- Can an effective flood barrier be constructed using wooden pallets and a waterproof membrane?
- How do two alternative configurations perform: modules consisting of three pallets and modules consisting of two pallets?
- Is the concept suitable for practical deployment, and what limitations are encountered?
- How can an effective connection be achieved to 1V:1H embankment slopes and at right-angle bends?
- How does the system perform on uneven terrain, including the soft and waterlogged ground conditions encountered on Day 2?
- How resistant is the system to vandalism and accidental damage, for example from floating debris such as tree trunks?
- How easily can the installation procedure be explained, and what are the deployment rate and manual transport requirements for a transport distance of approximately 40 m?
- How does the pallet barrier perform under overtopping conditions?
- How stable is the barrier under different loading conditions (unloaded, partially loaded and fully loaded)?
- How quickly can the barrier be dismantled and made ready for redeployment, and what level of leakage can be expected?

1.3.2 HAAWAL

The objective was to construct approximately 20 m of mobile flood barrier on uneven ground, including at least one right-angle bend and a reliable connection to other mobile flood defence systems.

Learning objectives

- To become familiar with the system, its practical applicability and its operational limitations.
- To assess how effectively the system can be connected to other mobile flood defence systems and whether reliable right-angle transitions can be achieved.
- To evaluate the performance of the system on uneven terrain, including soft and waterlogged ground conditions.
- To assess the resilience of the system to vandalism and accidental damage, such as impact from floating debris (e.g. tree trunks).
- To evaluate the ease of explaining and implementing the deployment procedure, as well as the achievable installation rate.
- To assess the performance of the mobile flood barrier under overtopping conditions.
- To evaluate the stability of the system under different loading conditions (unloaded, partially loaded and fully loaded).
- To assess the time required to dismantle the barrier and prepare it for redeployment.
- To determine the expected leakage rate of the system.

1.3.3 BUITINK FLEXIBLE WATER DAM AND TUBEBARRIER

The objective was to install two 10 m sections of mobile flood barrier as a secondary defence line behind an existing flood defence system on uneven ground, including a connection

to another mobile barrier system and a reliable transition to an embankment slope with a gradient of approximately 1V:1H. The target water retention height was 0.6 m.

Learning objectives

- To become familiar with the system, its operational applicability and its limitations.
- To assess how effectively the system can be connected to other mobile flood defence systems and whether reliable right-angle bends can be incorporated.
- To evaluate the effectiveness of transitions to embankment slopes with a gradient of 1V:1H and to other mobile flood defence systems.
- To assess the performance of the system on uneven terrain, including the soft and water-logged ground conditions encountered on Day 2.
- To evaluate the ease with which deployment procedures can be explained and implemented, as well as the achievable installation rate.
- To assess the stability of the system under different loading conditions (unloaded, partially loaded and fully loaded).
- To evaluate the performance of the system under overtopping conditions.
- To assess the time required to dismantle the system and prepare it for redeployment.
- To determine the expected leakage rate of the system.

1.4 OBJECTIVES FOR SLOPE PROTECTION COVERINGS

Exercise objectives

- To practise the installation of different types of slope protection coverings.
- To gain experience with various methods for securing slope protection coverings to an embankment slope.

Learning objectives

- To evaluate the clarity and effectiveness of the work instructions.
- To assess the practicality of the installation methods and the speed of deployment.
- To determine the most efficient approach for removing and recovering the slope protection coverings following deployment.

1.5 OBJECTIVES RELATED TO SANDBAGGING AND SANDBAG RING DIKES AROUND A SAND BOIL

Exercise objectives

- To construct a temporary flood defence using sandbags on a narrow embankment crest.
- To practise the safe transport of sandbags down a steep and slippery embankment slope (1V:1H) using either a foil slide or a timber chute fitted with mesh and wooden cleats.
- To practise dismantling the sandbag structure and stacking the sandbags in an orderly manner following the exercise.
- To construct a circular sandbag ring dike around a sand-producing boil.

Learning objectives

- To evaluate the use of the Sandbagging Handbook by both instructors and participants.
- To gain practical experience working within a sandbag chain.
- To familiarise participants with the innovative Wellenhoed, Wellenmatras and Sand Boil Filter Kit techniques for mitigating sand-producing boils associated with piping.

2

MOBILE FLOOD DEFENCE SYSTEMS

2.1 OBSERVATIONS ON THE EURO-PALLET FRAME SYSTEM

Frame systems constructed from Euro pallets proved to be effective mobile flood barriers and represent an easily improvised emergency measure using materials that are readily available or can be procured quickly and in large quantities. A Euro pallet (officially: EUR pallet) is a standardised wooden pallet widely used throughout Europe for the transport and storage of goods. It consists of a top deck and bottom deck separated by wooden blocks.

- Dimensions (L × W × H): 120 × 80 × 14.5 cm
- Weight: approximately 25 kg
- Load capacity: at least 1,500 kg

As an alternative, industrial pallets (120 × 100 cm) could also be considered. These are wider, dimensionally stable and durable plastic pallets, available with either an open or a closed deck. Since the pallets are installed with the narrow side facing upwards, the use of industrial pallets would allow an even greater barrier height to be achieved.

Figure 2.1 Euro pallets



TWO-PALLET CONFIGURATION

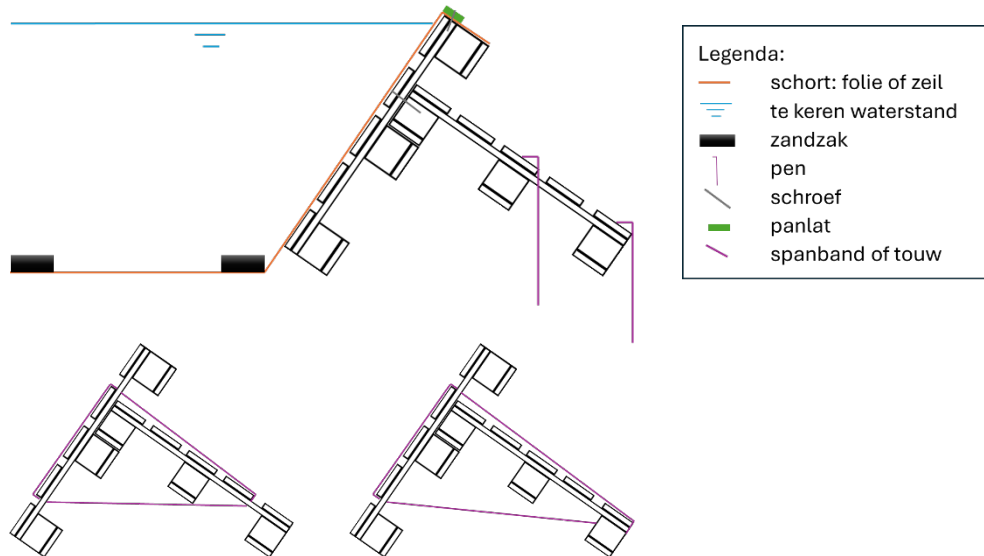
In the two-pallet configuration, two pallets are positioned at right angles to form an A-frame structure, with one pallet interlocking with the opening of the other. The pallets are connected using three screws at the locations where the vertical deck boards of one pallet come into contact with the spacer blocks of the other pallet. The higher side of the structure is oriented towards the water side, where the impermeable liner is also placed.

Each module consists of two pallets, which can be connected either with screws or with ratchet straps.

To prevent movement of the structure, the rear of the two-pallet configuration is anchored to the ground using two steel pins or ground staples. These can be driven directly against the pallet, although installation through the pallet openings is preferred, as this effectively prevents any displacement of the structure.

Figure 2.2

Principle layout of the two-pallet configuration



The impermeable liner, for example tarpaulin, may alternatively be wrapped over the entire structure and extended to the toe of the supporting pallet in order to minimise saturation and erosion of the ground surface behind the barrier.

Figure 2.3

Principle layout of the two-pallet configuration with the tarpaulin extending to the toe of the supporting pallet

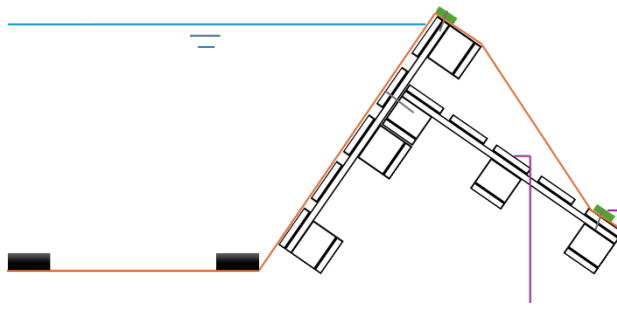


Figure 2.4

Two-pallet configuration. The pallets are anchored on the landward side (i.e. non-water-retaining side) using steel pins to prevent movement of the structure.

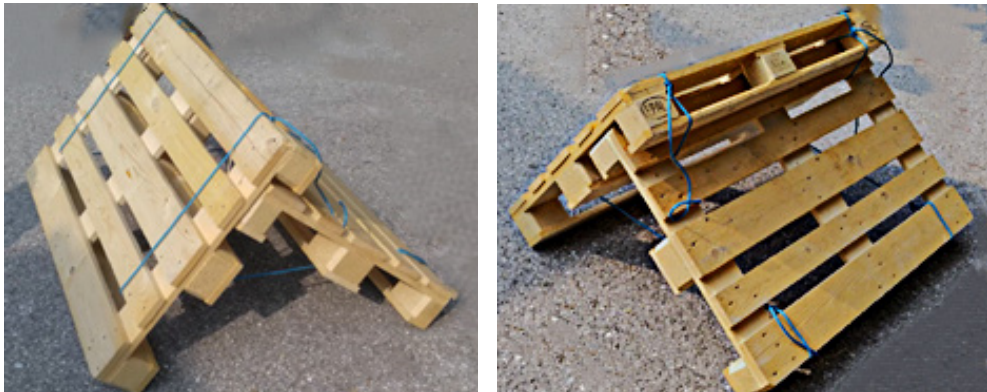


Figure 2.5 Long L-shaped ground pins



Alternatively, the modules of two pallets may be connected by means of two ropes or ratchet straps. The ropes are attached to the upper cross member of the retaining pallet and the lower cross member of the supporting pallet, and are subsequently routed through the lower openings of both pallets. The resulting tensile force stabilises the open space between the pallets and ensures the structural stability to the configuration.

Figure 2.6 Alternatively, the pallet assembly can be stabilised by means of ropes or tensioning/ratchet straps.



Passing the ropes or tensioning straps through the lower openings from the front to the rear of the structure proved challenging. The process could potentially be facilitated by using a pole equipped with a hook to guide and pull the ropes or straps through the openings.

Figure 2.7

The pallet system can also be configured to form basin structures and 90-degree corners. In such configurations, the internal corners should be strengthened with additional pallets, and the intervening space should be filled and stabilised with sandbags.



To improve the interconnection between individual modules, the retaining pallet and the rear supporting pallet can be arranged in a staggered (running bond) pattern.

In addition, the assembled modules can be connected using dedicated metal staples or connectors.

A sheet or tarpaulin is placed over the water-retaining modules to provide the watertight barrier. The sheet is firmly secured against the base of the pallets using sandbags and is then extended approximately 2 m away from the structure on the water side. The edges of the sheet are ballasted with sandbags. Alternatively, the end of the sheet can be wrapped around timber battens and anchored to the ground using U-shaped ground staples.

At the crest of the pallet structure, the sheet is secured with sandbags. Alternatively, timber battens can be rolled into the sheet and fastened to the pallets using screws. In this case, the sheet should be rolled towards the protected side of the structure to prevent the formation of gaps where overtopping water could gain access and compromise the seal.

The advantage of the two-pallet system is that fewer pallets are required. However, a disadvantage is that the achievable retaining height is lower than that of a three-pallet system, in which the water-retaining face is positioned almost vertically.

3-PALLET METHOD:

In the three-pallet system, one pallet is placed upside down on the ground, while the other two pallets are positioned in the space above it in an A-frame configuration. The two inclined pallets are placed against each other in such a way that they interlock.

A staggered arrangement (running bond) between adjacent two-pallet and three-pallet modules, in which the vertical joints between pallets are offset by half a pallet width, can only be achieved when screws are used if sufficiently long screws are available. This is because a force-transferring connection between the deck boards of one pallet and the spacer blocks of the adjacent pallet, where structural integrity is provided through force transfer and friction, cannot always be achieved in this configuration. Timber battens are rolled into the sheet in such a way that overtopping water can flow smoothly over the sheet and cannot accumulate in the recess formed by the rolled-up section of the sheet.

Figure 2.8

Schematic configuration of the three-pallet system

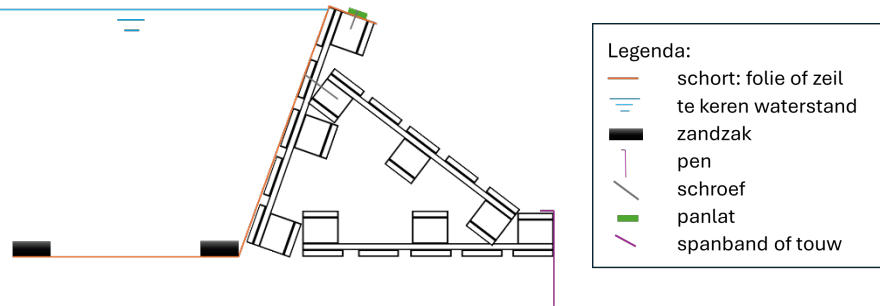


Figure 2.9

Alternative configuration of the three-pallet system, with the impermeable sheet extending to the rear side of the structure.

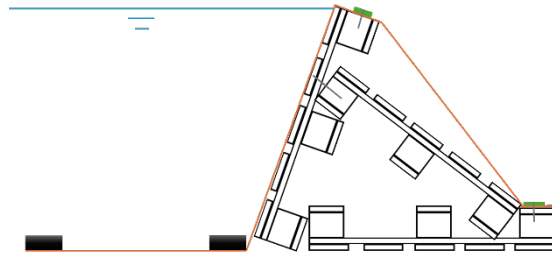


Figure 2.10

Inverted base pallet with an inclined pallet on the water-retaining side.



Figure 2.11

A third pallet is positioned behind the water-retaining pallet as a brace, with its base secured within the inverted pallet placed on the ground. The stability of the system against sliding is achieved through the frictional resistance of the inverted base pallet.



Figure 2.12 Base pallet arranged in a staggered (running bond) pattern relative to adjacent pallets.



Figure 2.13 To enable curved sections or 90-degree changes in direction, an additional pallet is placed on its narrow edge at the corner location. The spaces between the pallets are filled with sandbags to ensure stability and continuity of the structure. The impermeable sheet should additionally be clamped beneath the pallets to prevent uplift of the sheet under hydraulic loading.



On smooth surfaces, the system requires fixation to prevent sliding.

Figure 2.14 Each three-pallet module is held together by ratchet straps wrapped around the entire module. Left: supported side; right: the same situation viewed from the water-retaining side.



Figure 2.15 The three-pallet modules are interconnected in a staggered bond arrangement using metal clamps.



Figure 2.16 An L-shaped configuration of three-pallet modules. The corner is reinforced using an additional pallet fixed in place with metal clamps.



Figure 2.17 The Euro pallets are interconnected using robust, short steel U-clamps (staples).



Figure 2.18 Sandbags are used to fill gaps at corners and slope transitions.



The combined use of two-pallet and three-pallet modules is not recommended due to the difference in barrier height between the two systems. The two-pallet system provides a lower crest level as a result of the absence of a base pallet and the larger angle between the water-retaining pallet and the supporting pallet.

Figure 2.19 A two-pallet module connected to a three-pallet module in a staggered bond arrangement. The connection is complicated by the absence of a base pallet in the two-pallet system and its lower overall height. Left: supporting side; right: water-retaining side.



Figure 2.20 The connection between the water-retaining and supporting pallets is achieved using screws driven through the deck boards of the water-retaining pallet into the blocks of the supporting pallet.



Figure 2.21 The transition between the pallet structure and the dike slope presents a greater challenge. Right: a chute made from plastic sheeting, used to facilitate the placement of sandbags at the toe of the dike.



Figure 2.22 Placement of the Euro pallets at the slope transition is more challenging because the elements do not interlock properly in a staggered bond arrangement. Sandbags are required to seal the gaps to the ground surface and provide stability, while the pallets are secured together using steel staples.



Figure 2.23 In the three-pallet configuration, the sheeting is primarily fixed in place using sandbags, both at the crest of the temporary flood barrier and directly against the pallets on the water-retaining side. The sheeting should be laid flat on the ground surface without wrinkles and ballasted along its perimeter with sandbags to prevent seepage beneath the barrier.



Figure 2.24 The plastic sheeting is secured at the top of the two-pallet system using screwed timber battens.



Figure 2.25 The opposite end of the plastic sheeting is rolled around timber battens and fixed to the ground using steel staples. The sheeting should be laid flat on the ground surface, avoiding trapped air and wrinkles as much as possible.



A less suitable configuration for anchoring the plastic sheeting with timber battens is illustrated in the figures below. Here, the battens are rolled towards the water-retaining side, resulting in a depression where overtopping water can accumulate.

Figure 2.26 The timber battens have been rolled into the plastic sheeting in the wrong direction at the top of the Euro pallet structure, creating a depression in which overtopping water can accumulate.



The following figures show the implementation of the Euro pallet systems during the second day of the exercise. A more suitable method for rolling the timber battens into the plastic sheeting is demonstrated. The battens are rolled towards the non-water-retaining side and subsequently secured with screws.

Figure 2.27 The timber battens are rolled into the plastic sheeting towards the dry side of the structure. This results in a smooth and wrinkle-free surface, allowing overtopping water to pass more readily over the barrier.



The figure below clearly demonstrates the importance of adequately securing the plastic sheeting against the pallet structure and along the ground surface with sandbags. Owing to its low weight, the sheeting is highly susceptible to being lifted by wind if not properly fixed in place.

Figure 2.28

De dunne folie is heel licht en waait daarom snel op. Het is belangrijk de folie goed op de grond tegen de palletconstructie aan te fixeren en erop te letten dat er weinig plooiën en lucht in zit.



Filling the basin:

Figure 2.29

The L-shaped Euro pallet basin was filled with water via a hose routed over the clamped connection. Leakage occurred at the landward side of the Euro pallet barrier at an early stage, despite the limited water level in the basin. The leakage was caused by tears in the plastic sheeting, which had developed as a result of personnel walking on the relatively thin material, thereby compromising the integrity and watertightness of the sheeting.



Figure 2.30

The structure remained stable, even at higher water levels and during overtopping.



Figure 2.31 The basin is filled further until the overtopping flow from the Euro pallet structure also fills the space between the Euro pallet barrier and the TubeBarrier located behind it. The water then enters the TubeBarrier through the openings on its water-retaining side, resulting in the filling of the tube.



Figure 2.32 The Euro pallet basin after cessation of the water supply. The water level in the basin gradually decreased over time due to a combination of underseepage beneath the barrier and leakage through the plastic sheeting.



The following figures show the performance of the pallet barrier during the second day of the exercise. The plastic sheeting remained in better condition because personnel exercised greater care when walking on it. As a result, the observed leakage was mainly attributable to underseepage rather than damage to the sheeting itself.

Figure 2.33 Test of the Euro pallet barrier on the second day of the exercise. Compared with the first day, the barrier showed improved watertightness and reduced leakage.



Figure 2.34 Performance test of the Euro pallet barrier during the second day of the exercise. The barrier remained stable under overtopping conditions, with no signs of instability or structural displacement.



Figure 2.35 Following cessation of the water supply, the water level decreased only gradually, indicating a relatively high degree of watertightness of the barrier system.



Consideration could be given to extending the plastic sheeting over the crest of the pallet structure towards the protected side. This may help to reduce softening and potential erosion of the ground surface beneath and behind the pallets as a result of overtopping flow.

2.2 OBSERVATIONS ON THE TUBE BARRIER

Figure 2.36 Transport and unpacking of a TubeBarrier from its protective cover.



Figure 2.37 The 10 m TubeBarrier modules are connected to form a continuous barrier. During repositioning of the extended “TubeBarrier accordion”, operators experienced difficulty obtaining a secure grip on the system. The absence of handles or lifting loops on the upper surface makes it cumbersome to rotate or reposition the TubeBarrier during deployment.



Figure 2.38 During repositioning of the TubeBarrier, a drainage pipe on the underside of the system was inadvertently pulled out, indicating the vulnerability of this component during handling.



Figure 2.39 Two TubeBarrier modules connected by means of Velcro fasteners.



Figure 2.40 Installation of anchor plates in the water-side skirt of the TubeBarrier to mitigate underseepage.



Figure 2.41 The TubeBarrier anchored against the slope by means of ratchet straps.



Figure 2.42 The TubeBarrier skirt was deployed, but owing to the limited space available relative to the Euro pallet barrier, it could not be laid flat on the ground surface and consequently contained multiple folds. The outer edge of the skirt was weighted down with sandbags to mitigate underseepage beneath the barrier.



Figure 2.43 The highly irregular contact between the sheeting and the grass-covered ground surface is clearly visible, which may adversely affect the watertightness of the barrier.



Figure 2.44 The space between the Euro pallet barrier and the TubeBarrier was filled with water. The ground surface on the protected side of the TubeBarrier showed clear signs of saturation due to underseepage beneath the barrier.



Figure 2.45 After completion of the test, the TubeBarrier system was disassembled. The process required substantial manpower, as the tube first had to be fully drained before the system could be removed and packed.



When the TubeBarrier was tilted as shown in Figure 2.45, water drained only slowly because the skirt obstructed the outlet openings. Improved drainage was achieved by tilting the barrier in the opposite direction or by pulling the TubeBarrier up the dike slope, as illustrated in the figures below.

Figure 2.46 Residual water remaining in the TubeBarrier after drainage. The remaining water significantly increases the weight of the system, making handling and repositioning difficult.



Figure 2.47 Complete removal of the residual water was achieved by turning the TubeBarrier upside down and placing it on a slope, allowing the remaining water to drain from the system.



Figure 2.48 Drainage and venting pipes located beneath the TubeBarrier skirt. Their function is to release trapped air and water, thereby preventing uplift of the barrier and promoting good contact between the skirt and the ground surface.



Figure 2.49 Folding, packing, and loading of the TubeBarrier.



2.3 OBSERVATIONS ON HAAWAL

Figure 2.50 36 Haawal panels per pallet.



Figure 2.51 The modules feature a central opening, allowing them to be easily carried with one hand.



Figure 2.52 Installation of the Haawal system with a curved alignment.



Figure 2.53 Construction details at the transitions to the dike slopes.



Figure 2.54 The guy wires are attached to the base plate by means of a screw fitting installed in the opening indicated in orange.



Figure 2.55 The two photographs are included solely to illustrate the attachment of the guy wires to the grating panels. The guy wires are routed over the top of the vertically positioned barrier panel and anchored at the rear in one of the square openings. In the curved configuration shown in the photograph on the right, the guy wires are in some cases connected not to the panel of the same module but to that of an adjacent module. It is questionable whether connecting modules in this manner provides any benefit. The primary function of the guy wires is to enhance the stability of each individual module, particularly against dynamic loads, given the inherently rigid nature of the system. During actual deployment, a plastic membrane is first placed over the grating panels, after which the guy wires are fastened through the membrane using screw fittings.

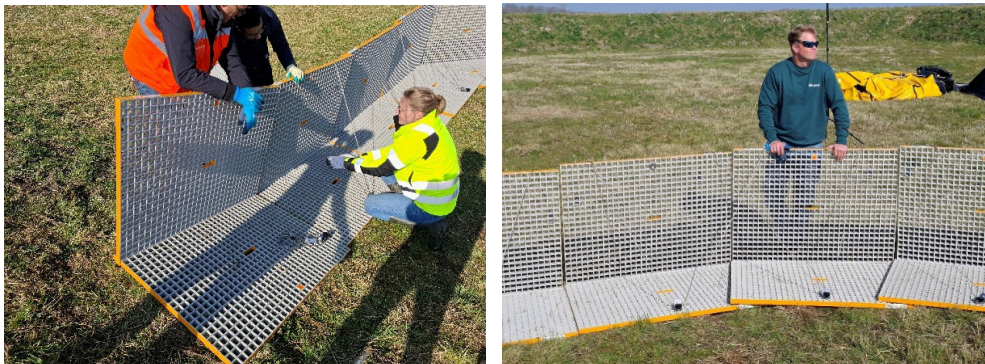


Figure 2.56 Placement and unfolding of the waterproof membrane and pressing it into the internal corner.



Figure 2.57 The outer edge of the membrane is ballasted with sandbags to reduce underseepage beneath the barrier. It is noticeable that the membrane still contains a considerable number of folds.



Figure 2.58 “In some locations, a considerable gap is present between adjacent modules, leaving the membrane as the only watertight barrier at these transitions. It is further observed that the guy wires are anchored at seemingly arbitrary locations on the rear side of the panels.”

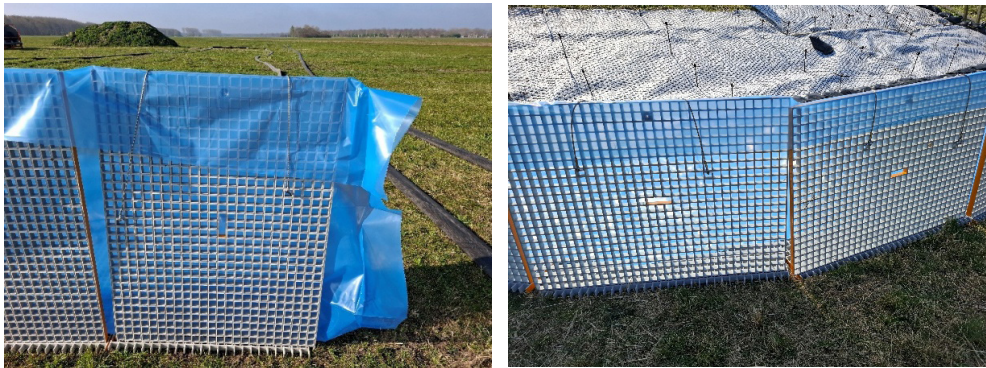


Figure 2.59 Water filling of the curved Haawal barrier configuration.



Figure 2.60 The basin has not yet reached its full design water level. Nevertheless, underseepage is already evident at the lateral transitions between the barrier and the embankment slopes.



Figure 2.61 The rate of underseepage-induced leakage increases as the retained water level rises.



Figure 2.62 The barrier has been filled to its upper edge, and overtopping has commenced.



Figure 2.63 Following cessation of the inflow, the water level in the Haawal basin gradually decreases as the basin drains.



Alternative U-shaped configuration of the Haawal basin on the second day of testing:

Figure 2.64

The basin is now arranged in a more rectangular configuration without curved sections.



Figure 2.65

Also in this configuration, the guy wires are not anchored to the rear side of the panels in accordance with the supplier's installation instructions. Some wires are routed horizontally around the corner and connected to the adjacent panel. These wires do not appear to be under tension and can be moved vertically with little effort.



Figure 2.66

Filling of the Haawal basin with water. On the right-hand side, signs of seepage-induced wetting are already visible in the grassed area landward of the barrier, indicating underseepage beneath the structure.



Figure 2.67 The Haawal basin has been filled to crest level, and overtopping has commenced.



Figure 2.68 Following cessation of the water inflow, the system was able to maintain the retained water level for a considerable period. The Haawal system proved to be highly shape-stable under load. No adverse effects were observed at locations where adjacent panels were not perfectly aligned and visible gaps were present between modules.



Figure 2.69 As part of the test, a volunteer wearing chest waders used a knife to create a long tear in the membrane at a location where a gap was present in the Haawal barrier.



Figure 2.70 The tear extended over approximately two-thirds of the barrier height.



Figure 2.71 A high-intensity flow of water emerged through the tear, but no further growth of the tear was observed.



Figure 2.72 The tear was mitigated by positioning an additional membrane sheet against the two vertical panels on the water side of the barrier. This intervention resulted in a significant reduction in leakage.



Figure 2.73 The membrane is fixed against the inner face of the L-shaped module using a sandbag. This measure reduces the leakage to a negligible level.



2.4 OBSERVATIONS ON THE PERFORMANCE OF THE BUITINK FLEXIBLE WATER BARRIER (BFW)

Figure 2.74 Buitink Flexible Water Barrier in its original storage sleeve. Installation instructions are provided on both the sleeve and the module.



Figure 2.75 The connection of two modules requires the individual layers to be joined using hook-and-loop fasteners. This process is labour-intensive and susceptible to assembly errors, as one or more layers can easily be overlooked during installation.



Figure 2.76 To maintain the BFW system in its deployed configuration prior to filling, support brackets are installed to keep the structure upright in the absence of water.



Figure 2.77 Left: Interface between the BFW system and a TubeBarrier, and between the BFW system and a Europallet Barrier, at the transition to the dike slope.



Figure 2.78 Close-up view of the connection between the BFW system and the TubeBarrier. Left: water side; right: protected side.



Figure 2.76 illustrates the challenges associated with connecting the BFW and TubeBarrier systems. These challenges are mainly caused by differences in the retained water height of the two systems, as well as by differences in their cross-sectional profiles and end-section configurations. The rope connection results in substantial deformation of both barriers. Sandbags were installed between the systems to improve watertightness at the interface. It is further observed that the ends of both systems have been pulled downward, potentially creating a local weak spot in the flood defence line with respect to both structural stability and overtopping resistance.

Figure 2.79 The area between the Haawal barrier and the Buitink Flexible Water Barrier (BFW) gradually fills with water, indicating leakage at the interface between the two systems.

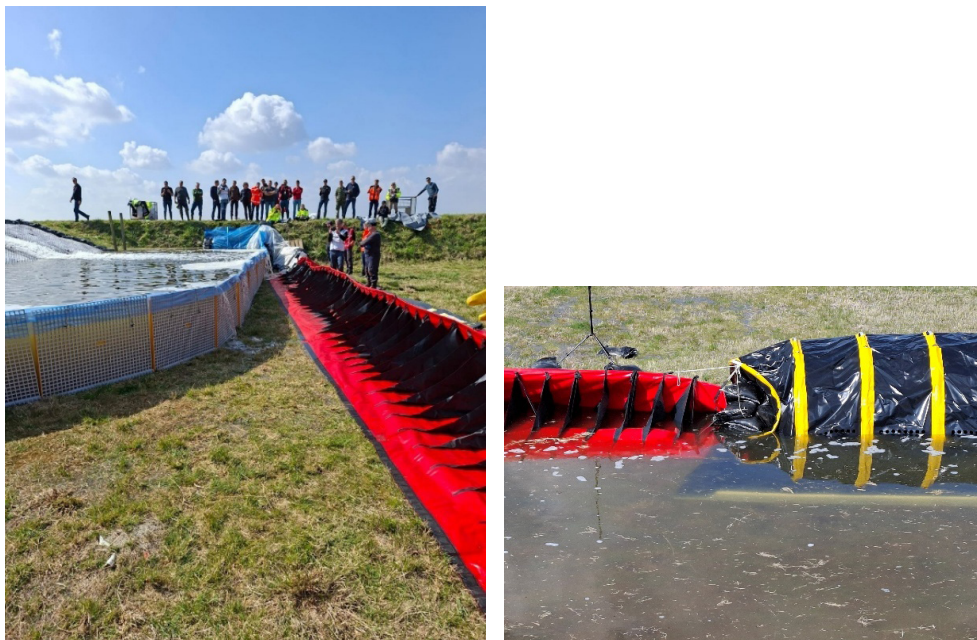


Figure 2.80 On the landward side of the BFW, leakage is observed as a result of underseepage beneath the barrier. Because the waterside edge of the membrane was not ballasted with sandbags, the membrane partially lifted under hydraulic loading, allowing water to pass beneath the system.



BFW system configuration on the second day of testing:

Figure 2.81 The BFW system is positioned diagonally within one corner of the basin, connecting the two embankment slopes.



Figure 2.82 To improve the interface between the BFW and the dike slope, sandbags were positioned against the barrier. Additional sandbags were placed on the ground covering to provide ballast and enhance contact with the subsoil. Water was then introduced over the Tensar geogrid-reinforced section.



Figure 2.83 Underseepage is also observed in this configuration. In addition, part of the flow bypasses the barrier along the edges, notwithstanding the sandbag sealing applied at these locations.



Figure 2.84 To accelerate the release of the water retained by the BFW, the discharge openings incorporated into the barrier were opened by pulling apart the hook-and-loop fastener seals.



Figure 2.85 Although the grass had been cut approximately three weeks before the exercise, a considerable amount of vegetation became trapped in the BFW system during deployment. The subsequent cleaning of the system was found to be very labour-intensive.



Figure 2.86 Rolling up and cleaning the BFW system.



Figure 2.87 Following the exercise, the BFW had to be thoroughly cleaned with water before it could be prepared for storage.



Figure 2.88 Inspection after the exercise revealed that one of the seams had ruptured during use.



2.5 CONCLUSIONS AND RECOMMENDATIONS FOR THE APPLICATION OF MOBILE FLOOD BARRIERS

2.5.1 CONCLUSIONS AND RECOMMENDATIONS FOR THE EUROPALLET FRAME SYSTEM

- The Europallet systems performed surprisingly well and remained highly stable, even under overtopping conditions.
- This type of mobile flood barrier was well received by all participants. It is flexible, quick to install, the required materials are often readily available, and the costs are minimal.
- A 15 m long pallet barrier was installed in 12 minutes by a team of seven people.
- The 6 cm screws used during the exercise were occasionally too short. The use of 10 cm screws is recommended.
- It is recommended to make more cordless screwdrivers available in order to accelerate the installation process.
- The two-pallet configuration could be assembled more quickly than the three-pallet configuration but required more time for dismantling because the screws were difficult to remove. The staples could be removed more rapidly.
- Further optimisation of the screw connections may be beneficial from a time-efficiency perspective. Additional investigation is recommended to determine the minimum required screw length, the loads acting on the screws, and whether three screws per module are actually necessary.
- Fixing the pallets with short staples proved to be a faster installation method.
- When connecting pallets using ropes or ratchet straps, it can be difficult to pass the ropes or straps beneath the structure. It may be more efficient to pull the straps underneath the pallets using a pole equipped with a hook.
- Combining the two-pallet and three-pallet systems is not recommended. Owing to its structural configuration, the two-pallet system provides a slightly lower crest height than the three-pallet system. In addition, difficulties arise at the transition between the two systems, particularly when a staggered bond pattern is used. Any voids beneath the transition should be filled with sandbags.
- Creating a satisfactory transition between a Europallet barrier and an embankment slope can be challenging, particularly when a staggered bond arrangement is employed.
- Ground anchors may be more effective when installed between the pallet boards rather than at the lower ends of the pallets. This provides improved anchorage and reduces movement within the structure.
- The membrane used with the Europallet system was too thin. During the installation of the barrier, particularly on the first day, tears developed as personnel walked across the membrane, resulting in leakage during filling of the test basin.
- During deployment, the membrane should be laid tightly against the ground surface and free from folds in order to minimise water flow beneath the barrier.
- The membrane should be securely fixed against the underside of the pallet structure with sandbags to prevent wind uplift.
- Once the screws have been tightened, it becomes difficult to reposition modules in a staggered layout. Particular attention should be paid during placement of the membrane to ensure close contact with both the structure and the ground surface, while avoiding folds and preventing damage to the membrane. It may be advantageous to carry out the installation activities in a more sequential manner to allow for adjustments during construction. For example, the base pallets could first be positioned along the intended defence line, followed by placement of the upper pallets, then fixation of the assembly, and finally installation of the membrane.
- Additional testing with floating debris impacting the barrier is recommended.

2.5.2 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE TUBE BARRIER SYSTEM

- The system can be unfolded quickly; however, a considerable number of additional manual operations are required afterwards.
- Once fully deployed, the system is difficult to transport or reposition. No dedicated handles are provided, making it difficult to grip the TubeBarrier safely. As a result, there is a significant risk of accidentally pulling out one of the vent hoses.
- Several participants found it difficult to insert the anchor plates during installation.
- The anchor plates are also difficult to slide into position. This is likely to be even more challenging during winter conditions when personnel are working with cold hands, compared with the favourable weather conditions during the exercise.
- Installation instructions were not readily available during deployment. It is recommended to display the instructions directly on the modules themselves, similar to the approach used for the Buitink system.
- The system is relatively heavy and therefore difficult to move once unfolded. The absence of suitable handles means that the system can only be gripped at the lifting eyes located adjacent to the drainage hoses, creating a risk of damaging or disconnecting these hoses. The drainage hoses are positioned beneath the membrane to remove water trapped under the system and thereby improve contact with the ground surface. These hoses do not extend completely beneath the membrane, preventing a direct hydraulic connection with the water on the waterside of the barrier.
- Deployment of the TubeBarrier proved to be labour-intensive. There are doubts as to whether the system can be deployed effectively on uneven terrain.
- Repositioning the system after deployment is difficult because of its weight and the lack of suitable lifting points or handles.
- Recovery of the TubeBarrier proved to be particularly labour-intensive. During dismantling, a considerable volume of water remained trapped within the tubes. It was difficult to drain the modules completely. The modules remained very heavy and had to be placed upside down on a slope to allow the remaining water to drain.
- Folding the modules after use was also found to be difficult.
- Overall, the participants were not positive about the handling characteristics and operational performance of the TubeBarrier system.

2.5.3 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE HAAWAL SYSTEM

- The Haawal system is compact and easy to deploy.
- Each panel features a clearly visible orange marking indicating the location where the guy wires must be attached. This marking also indicates which side of the panel should face upwards during installation. Nevertheless, this detail was frequently overlooked during deployment. Because the cable connections can only be secured on the marked side, incorrect placement of the panels can result in significant delays. Since the membrane is placed over the modules before the guy wires are attached, incorrectly oriented panels may need to be turned over at a later stage.
- Suggested improvement for the Haawal system: redesign the cable anchorage so that guy wires can be attached from either side of the grating panel. This would eliminate problems associated with incorrect panel orientation during installation.
- When anchoring the guy wires at the rear of the modules, care should be taken to ensure that the wires are properly tensioned. If the wires remain loose, there is a risk that the anchorage may become detached and the system will no longer be able to resist horizontal loads effectively.
- The guy wires constitute a potential vulnerability within the system. They form a weak

link because it is not always clear in which openings at the rear the wires should be secured. If they are not properly engaged, the wires may work loose. In addition, debris such as driftwood may become entangled in the wires.

- During the installation of curved sections and right-angle corners, participants often routed the guy wires to adjacent modules instead of anchoring them behind the vertical panel of the respective module, as intended by the supplier. As a result, the wires were frequently not properly tensioned and could easily become detached. Despite the relatively untidy installation of the Haawal barriers on both test days, the barriers remained stable during overtopping. This raises the question of whether adjacent modules need to be interconnected at all. However, the stability of the individual modules can no longer be guaranteed under such circumstances, as the guy wires are specifically intended to transfer horizontal loads within each module. By connecting adjacent grating panels instead, optimum load transfer may no longer be achieved. This could have a negative effect under dynamic loading conditions, for example when impacted by floating debris.
- During dismantling, it is more efficient to first disconnect all guy wires from the rear anchorage points and leave them attached to the base plates. In a second step, the connections at the base plates can be removed. The wires can then be collected quickly while walking along the barrier line, reducing unnecessary handling operations.

2.5.4 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE BUITINK FLEXIBELE WATER BARRIER (BFW)

- Connecting the elements using the multi-layer hook-and-loop fastening system is physically demanding. Installation would be easier if an industrial-grade zipper connection were used instead. Such a solution would also be less susceptible to contamination by dirt and vegetation.
- The multi-layer arrangement of hook-and-loop fasteners and membrane layers is prone to installation errors. During assembly, one of the overlapping flaps can easily be overlooked. In such cases, a proper connection cannot be achieved, significantly increasing the risk of leakage.
- Once connected, the assembled elements are difficult to reposition.
- The vertical elements of the system are susceptible to tearing.
- When the system was deployed without sandbag ballast along the edges, considerable amounts of air became trapped beneath the membrane. This caused parts of the membrane to float, resulting in substantially increased underseepage. The performance improved noticeably when sandbags were used as ballast.
- The BFW system has only limited application flexibility. Direct connection to the TubeBarrier system proved unsuccessful because of differences in retained water height and incompatibility between the cross-sectional geometries of the two systems. Securing the systems together using ropes caused the ends of both barriers to be pulled downward, thereby reducing the effective barrier height at the transition.
- Following the first filling test, the BFW had already accumulated large amounts of grass and vegetation. Recovery of the system and subsequent cleaning proved to be labour-intensive. As a result, decommissioning and storage preparation require considerable effort.
- The installation instructions printed directly on the BFW modules were regarded by participants as very clear and user-friendly.

2.5.5 CONCLUSIONS AND RECOMMENDATIONS REGARDING MEMBRANES IN GENERAL

- For all mobile flood barrier systems that rely on a membrane, sheet, or similar element—particularly when used as an apron to reduce underseepage—it is essential to ensure that

the membrane is properly secured to both the ground surface and the barrier structure. Care should also be taken to minimise folds and trapped air beneath the membrane in order to achieve a good seal.

- The membranes used by Haawal during the exercise were transparent. In urban flood defence applications, this may have psychological disadvantages, as people on the protected side can directly observe the retained water level. Furthermore, the transparency makes it more evident that the flood defence relies primarily on a relatively thin membrane. Such a membrane may also be more susceptible to vandalism.
- During installation of an emergency flood barrier, personnel should avoid walking on the membrane wherever possible, as this can easily cause damage and compromise water-tightness.
- The artificial tears introduced into the Haawal membrane (thickness 0.5 mm) during the exercise did not propagate spontaneously under loading.
- Damage to the Haawal membrane can be repaired from the water side by applying an additional sheet of membrane over the tear. The repair membrane should be secured at its lower edge against the module using sandbags to ensure an effective seal.

3

GEOTEXTILE COVERINGS

During the exercise, different methods for installing geotextile coverings on a dike were evaluated. The following configurations were tested:

- Geogrid secured with Y-pins (according to the work instruction Installation of Sand-Tight Fabric with Geogrid (waterside), version 1.1, Emergency Measures Wiki).
- Geotextile secured with timber battens and U-shaped staples (according to the work instruction Geotextile Covering, Rijn and IJssel Water Authority).
- Geotextile secured with U-shaped staples and rope (according to the work instruction Installation of Geotextile Covering, Aa and Maas Water Authority / Groot Salland Water Authority).
- Biodegradable erosion-control fabric secured with screws and wooden staples.

3.1 MATERIALS AND SYSTEMS

Figure 3.1 Timber battens (25 mm × 45 mm × 5 m)



Figure 3.2 Biodegradable erosion-control fabric fixed to the ground at the corners using screws. In operational applications, wooden pegs are typically used instead.



Figure 3.3 Various types of steel staples and anchoring pins. Left: L-shaped staple; centre: U-shaped staple; right: Y-pin.



Figure 3.4 Wooden anchoring pegs



Figure 3.5 Staple pullers used for removing anchoring staples.



Figure 3.6 Left: steel T-pins with an additional U-shaped staple. Right: U-shaped staple (10 cm wide, 30 cm long, 8 mm diameter).



Figure 3.7 Gripple ground anchors installed using a specialised adapter for a cordless screwdriver.



Figure 3.8 Theoretical briefing prior to the practical exercise.



Figure 3.9 Geotextile Installation Using Timber Battens and U-Shaped Staples.



Figure 3.10 Timber battens are rolled into the four edges of the fabric and anchored into the ground using U-shaped staples.



Figure 3.11 Left: timber batten being rolled into the side edge of the fabric. Right: timber battens positioned on the fabric and anchored to the ground using U-shaped staples.



Figure 3.12 Left: detail of an overlapped connection between two timber battens on the embankment slope. Right: detail of two timber battens installed side by side on the embankment slope. Participants considered the side-by-side arrangement to provide greater stability.



Figure 3.13 Performance testing of the timber batten reinforcement system subjected to overtopping flow.



Figure 3.14 Removal of the staples using different types of stake pullers.



Figure 3.15 Installation of a reinforced geotextile covering using Tensar geogrid (150 g/m² nonwoven geotextile) and Y-pins. The Y-pins shown have not yet been fully driven in. To ensure full contact with the geotextile and adequate fixation, the pins should be pressed down to the fabric surface (see Figure 3.17). Installation is carried out progressively by unrolling a section of geotextile, installing the pins, and then unrolling the next section.



Figure 3.16 Tensar geogrid reinforcement secured with Y-pins. The overlap between two geotextile sheets is fixed using U-shaped staples, while sandbags are used to press the sheet edges against the ground.



Figure 3.17 Performance testing of the Tensar geogrid reinforcement system subjected to overtopping flow.



Figure 3.18 Installation of a traditional reinforced geotextile covering, using a woven geotextile. Placement of 30 cm long L-shaped pins.



Figure 3.19 The geotextile is anchored by means of a high-strength rope that is looped around the anchoring pins. The rope is secured to an initial pin and subsequently unwound from the spool while being stretched across the geotextile surface.



3.2 OBSERVATIONS REGARDING GEOTEXTILE COVERINGS

- Installation of the Tensar geogrid system required approximately 5 minutes per geotextile sheet.
- Installation of the timber batten reinforcement system required approximately 30 minutes per geotextile sheet.
- Participants found the proper rolling of the timber battens into the crest-side edge of the geotextile relatively difficult, as the long crest section required several overlapping battens to be incorporated. However, once completed, the installation resulted in a neat and tightly secured covering. Despite these challenges, the timber batten method was still installed more quickly than the traditional rope-based reinforcement method. The Tensar

geogrid system proved to be the fastest and easiest method to install.

- Driving pins or staples through thicker geotextile materials may be difficult. Providing staples with sharpened points or pre-cutting small holes in the geotextile using a knife may facilitate installation. Any such measures should take safety considerations and potential damage to the geotextile into account.
- Selection of an appropriate staple puller depends on the height of the person using it.
- Participants considered the chain of the staple puller to be relatively coarse and cumbersome in use.
- Testing of both the timber batten reinforcement system and the Tensar geogrid reinforcement system under overtopping conditions did not result in any visible damage to the geotextile coverings.

3.3 LESSONS LEARNED AND RECOMMENDATIONS REGARDING GEOTEXTILE COVERINGS

1. The *Sandbag Handbook* provides a useful template for developing a work instruction. However, translating this approach to reinforced geotextile coverings is challenging because different methods are used by different water authorities, including:
 - a. Root barrier fabric, geogrids (various types), and membranes;
 - b. Timber battens, rope, and steel cables;
 - c. Pins, staples, and screws of varying lengths;
 - d. Different dimensions, materials, and installation configurations.
 - e. Consequently, careful consideration is required regarding the level of detail and the range of techniques that should be covered in a standard work instruction.
2. More illustrations and less text are desirable in work instructions. However, two important considerations were identified:
 - a. Producing high-quality technical illustrations requires considerable effort;
 - b. It must be clear whether a figure represents a plan view, side view, or cross-section.
3. Tensioning the geotextile from one direction is considered particularly important, as emphasised in the work instructions of Rijn and IJssel Water Authority (WRIJ). WRIJ has applied reinforced geotextile coverings that remained in place for periods of several months and, in some cases, several years (e.g. for the control of Japanese knotweed). In such situations, a tightly installed and well-connected covering is essential to minimise the effects of wind and water. It is therefore recommended to:
 - a. Work perpendicular to the slope, using the short side of the geotextile as the primary tensioning direction;
 - b. Establish a straight and taut upper edge parallel to the crest line;
 - c. Tension the geotextile downward from the crest towards the toe;
 - d. Avoid using the toe line as a reference because its position may vary.
4. Removal and recovery of reinforced geotextile coverings
 - a. If pins or staples remain in the ground for extended periods, their removal becomes considerably more difficult due to corrosion. This aspect was not represented in the exercise. Nevertheless, participants emphasised that the primary objective during installation should be ensuring immediate effectiveness, even if this results in additional effort during removal.
 - b. Participants suggested that, for large-scale recovery operations, pins could potentially be extracted using an excavator equipped with a long boom.
 - c. Lifting pins and staples was found to be easiest using a pickaxe. The staple pullers available during the exercise were generally regarded as less user-friendly. Their effectiveness depended partly on the height of the user relative to the length of the puller,

but also on the type of hook fitted to the device. In particular, the larger hooks were considered unsuitable for efficiently extracting staples.

3.4 PROPOSED IMPROVEMENTS TO WIKI WORK INSTRUCTIONS FOR GEOTEXTILE COVERINGS

- Wiki work instructions should also be made available as editable Word documents, allowing individual water authorities to reuse them as templates for their own procedures and to more easily add, modify, or remove photographs.
- The work instructions should primarily provide a generic structure consisting of standardised steps and illustrations, to which individual water authorities can add their own specifications, such as the use of cordless drills and organisation-specific screw bit sets (e.g. Phillips, Torx).
- The work instructions should provide an overview of the various reinforcement methods available, the situations in which they can be applied, and the organisations that currently use them.
- A decision tree or selection framework should be included to help users determine which reinforcement method is most appropriate for a given situation.
- Generic process steps should be defined, including:
 - Materials;
 - Required quantities;
 - Storage;
 - Transport;
 - Safety considerations, including:
 - Wind conditions during installation;
 - Installation in the presence of water, currents, or wave action;
 - Installation;
 - Removal;
 - Cleaning.
- Some of these aspects should be included directly in the work instructions, while others may be more appropriately incorporated into a separate guidance document.
- An assessment should be carried out to identify which generic illustrations are required for inclusion in the work instructions.
- A toolbox containing standardised procedures, illustrations, and supporting materials should be made available.
- Management of this toolbox should be organised through periodic reviews, for example by means of annual exercises.
- Knowledge gaps should continue to be identified and incorporated into future research agendas.

Safety Consideration Regarding Y-Pins:

During a separate exercise organised by Hoogheemraadschap De Stichtse Rijnlanden (HDSR), a failure occurred in a similar Y-shaped anchoring pin. The welded section of one pin fractured during installation, creating a potentially hazardous situation with a risk of personal injury. Although no injury occurred, the event was classified as a near miss.

HDSR subsequently concluded that continued use of this type of pin could not be considered sufficiently safe or justified.

The pin consists of two welded steel components connected through a relatively small weld area. Although the welds are manufactured with due care, complete elimination of the risk of weld failure cannot be guaranteed. In theory, enhanced quality control of the welds could

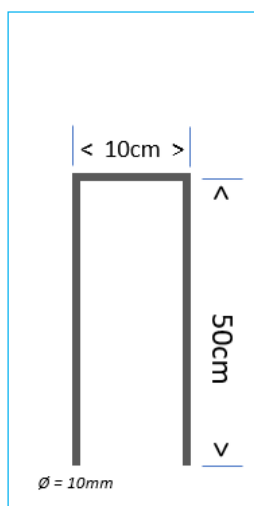
be implemented, for example through radiographic inspection. However, such measures would likely be costly and difficult to apply in practice. A further consideration is the high impact loading to which the pins are subjected during installation, as they are driven into the ground using heavy hammers. These impact forces act directly on the welded connection and may adversely affect its integrity.

For this reason, HDSR proposed phasing out the existing Y-pins and replacing them with a newly designed staple-type anchoring system (HDSR: Pins and Staples — Proposed Way Forward v1.0, 23 March 2026, registration number 2088600). HDSR recommends the future use of staples manufactured from 10 mm diameter reinforcing steel and having a length of 50 cm.

HDSR has developed a revised anchor design (see Figure 3.20 for an illustration) that addresses the various requirements from the perspectives of flood protection, safety, and cost-effectiveness.

- Flood Protection Performance
 - The revised staple design provides the required anchorage capacity, in accordance with the requirements presented in Table 1 (p. 31) of the Deltares report 11206793-009-ZWS-0003 — Reinforced Geotextile Covering Study, Living Lab Hedwige-Prosper Polder.
 - The staples are sufficiently wide to provide adequate fixation of the geotextile.
- Installation Safety
 - The risk of anchor failure is eliminated because the staple consists of a single steel element without welded connections.
 - Once installed, the staples do not leave protruding components above the ground surface, thereby reducing trip hazards.
 - Because the staples are manufactured from a single piece of material, they do not contain hidden defects. Damaged or unsuitable staples can be identified readily by visual inspection.
 - The absence of hidden defects also makes the staples suitable for safe reuse.
- Cost Considerations
 - The unit cost of an anchor is largely determined by the number of manufacturing operations required. A standard U-shaped staple typically costs in the order of €1 – 2 per unit, whereas a welded Y-pin costs approximately €8 – 10 per unit and will, in many cases, only be suitable for a single deployment.
 - The revised staple design therefore offers potential advantages not only in terms of safety and robustness, but also with respect to lifecycle costs and reusability.

Figure 3.20 Proposed anchoring staple ('HDSR-SLD design').



4

SANDBAGGING AND RING-DIKING OF SAND BOILS

The objective of this exercise was to improve participants' skills in transporting and stacking sandbags. One of the exercises involved the construction of a sandbag barrier. The following observations were recorded:

- To facilitate hand-to-hand transfer of sandbags in a human chain up a steep embankment slope, wooden boards fitted with transverse battens (covered with chicken wire) were placed on the slope. These boards provided stable footing for the participants.
- Sandbags should not be handled with bare arms; personnel should always wear long sleeves to prevent abrasions and skin irritation.
- The first person in the chain (i.e. the individual placing the sandbags) determines the working rhythm and therefore the overall transfer rate. The instructor should monitor this carefully.
- Participants should communicate in a timely manner when sandbags are being passed too quickly through the chain. In the event of a bottleneck, sandbags should be placed on the ground rather than held continuously in the arms, in order to avoid unnecessary fatigue.
- To facilitate the transport of sandbags from the crest to the toe of the dike, a sheet of membrane was placed on the slope and ballasted at the crest with sandbags. The sandbags could then slide down the membrane in a controlled manner, effectively creating a temporary chute.

Figure 4.1 Instruction on sandbag stacking techniques and the transfer of sandbags through a human chain on a slope. Stability and footing are improved by placing boards equipped with wire mesh and transverse cleats on the embankment slope.



Figure 4.2 A membrane, ballasted at the crest with sandbags, is used as a chute to facilitate the transport of sandbags to the toe of the dike slope.



Figure 4.3 The first layer of sandbags is installed with the tail of each bag overlapping the head of the preceding bag. Successive layers are placed in a staggered bond pattern, with the second and third layers offset relative to the first layer and the fourth layer offset relative to the third layer.



The second exercise focused on constructing a sandbag ring dike around an artificially created sand boil producing sediment-laden seepage water.

Figure 4.4 To simulate the appearance of a sand boil transporting sediment, water from a reservoir is conveyed underground through a hose to the centre of a sand-filled crater.



Figure 4.5 Instruction on the construction of a sandbag ring dike in accordance with STOWA's Sandbagging Handbook.



Figure 4.6 Construction of a sandbag ring dike, with each layer of sandbags compacted by walking on it to ensure good interlocking between the bags. The sandbags should not be tamped.



Three innovative techniques for the mitigation of sediment-carrying sand boils were also introduced during the exercise: the sand boil cap, the sand boil mattress, and the Sand Boil Filter Kit ("sand boil plug").

Figure 4.7 Sand boil cap as an alternative measure to sandbag ring dikes for the mitigation of sediment-carrying sand boils.



Figure 4.8

The sand boil cap is constructed from a rolled Tensar geogrid sheet. The lower section is folded inward, creating a circular opening at the bottom through which the sand boil can discharge.

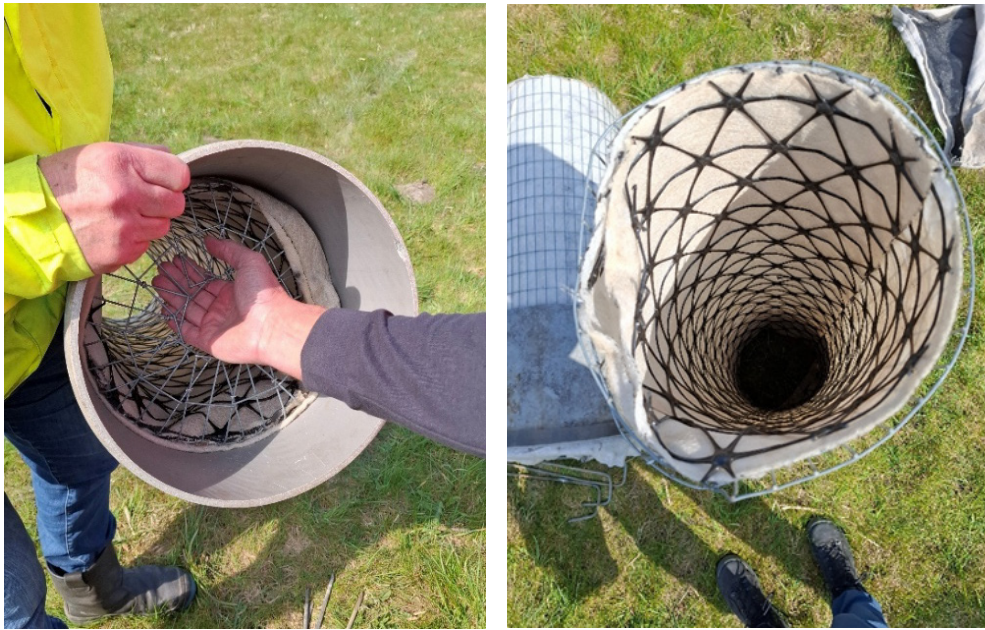


Figure 4.9

To enhance the structural stability of the sand boil cap, the geotextile is reinforced with an external wire mesh. The resulting cylindrical element is positioned within a PVC casing that allows vertical movement. During deployment, the PVC pipe is inserted into the sand boil.



Figure 4.10

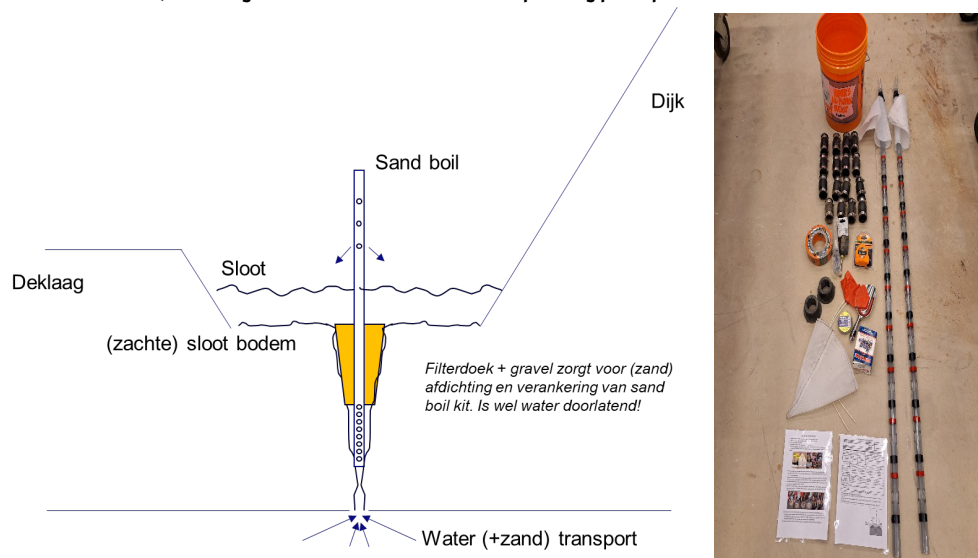
The sand boil mattress is constructed from a nonwoven filter geotextile (Tensar geotextile fleece) filled with granular filter material. When placed over a sand boil, the combination of geotextile and rock-fill filter material acts as a graded filter, preventing the discharge of sand particles while permitting seepage flow to continue.



Figure 4.11 The cushion element on the left-hand side of the sand boil mattress is filled with a fine granular filter material. The material consists of crushed mineral aggregate similar to that used as a protective surfacing on bituminous roofing sheets. This fine filter layer contributes to retaining sand particles while allowing seepage water to pass through.



Figure 4.12 Sand Boil Filter Kit, including a schematic illustration of its operating principle.



Het werkingsprincipe van de Sand Boil Filter Kit werd alleen toegelicht, maar kon niet fysiek worden gedemonstreerd.

Met de deelnemers werden de voor- en nadelen bediscussieerd en gevraagd of deze zouden kunnen worden getest als er echte zandmeevoerende wellen optreden.

5

LESSONS LEARNED: SUCCESSES AND AREAS FOR IMPROVEMENT

Figure 5.1 Group photographs of the participants in the exercise conducted on 14 and 15 April 2026.



Figure 5.2 Debriefing and evaluation following the second day of the exercise.



5.1 ORGANISATION OF THE EXERCISE (WORKING GROUP, STAFFING, PLANNING AND THEME)

What should be maintained (strengths) and what should be improved (areas for improvement)? These recommendations are intended to improve the efficiency, effectiveness, and educational value of future field exercises while maintaining the strengths identified during the April 2026 event.

Strengths:

- Special appreciation is due to the Ministry of Defence for making the exercise location available and for organising catering and refreshments. At least four Defence personnel (recognisable by their green uniforms) were present to provide logistical and operational support.
- The exercise management team consisted of a highly motivated and knowledgeable group of people. It is recommended to retain this core team while gradually involving younger colleagues in order to facilitate knowledge transfer and ensure continuity.
- More than 50 participants attended each of the two exercise days. This represented a strong turnout while still allowing effective coordination and supervision. Should participation increase further in future editions, consideration should be given either to adding a third exercise day or expanding the number of instructors and support staff.
- All instructors demonstrated considerable flexibility in their approach, allowing the programme to adapt to unforeseen circumstances and making improvisation possible when required.
- The participation of international attendees and managerial representatives was highly appreciated. Such exercises provide an excellent opportunity to raise awareness among water managers, colleagues, and decision-makers of the importance of field-based crisis management, training, and preparedness activities. They also demonstrate the ongoing national and international cooperation in knowledge development. In future exercises, it is recommended to invite additional managers and representatives of the High Water Protection Programme (HWBP), thereby broadening their exposure beyond traditional dike reinforcement projects.

Areas for Improvement:

- The preparation of the exercise could have been more structured and completed earlier. Discussions regarding the final exercise set-up were still taking place on the eve of the exercise. Future exercises would benefit from an earlier start to the preparation phase, a more structured planning process, and a realistic project schedule. A detailed review of all required activities should take place at least two weeks before the exercise.
- Dates for working group meetings should be scheduled and communicated well in advance to maximise attendance and avoid the need to revisit decisions or repeat discussions.
- The Emergency Measures Wiki should be involved from the outset, particularly with regard to the selection of techniques to be exercised and the formulation of learning and training objectives.
- A central checklist or planning document should be prepared in advance, clearly defining the objectives of the exercise and the intended learning outcomes.
- A designated person should be responsible for the preparation of each exercise component.
- Expectations regarding participants' contributions and learning outcomes should be discussed explicitly at an early stage.

- Greater effort should be made to familiarise participants with each other's terminology and operational practices, including those commonly used by Defence personnel.
- The maximum number of participants should be determined in advance. If demand exceeds capacity, it would be preferable to schedule an additional exercise day rather than accommodate excessively large groups. A maximum of approximately 50 participants per exercise day appears manageable. Registration could therefore be capped, with additional applicants placed on a waiting list.
- Consideration should be given to establishing a dedicated CTW exercise budget to support the organisation of such events. Participants should also receive more comprehensive information beforehand, including site-specific restrictions such as photography limitations.
- Preparations for the autumn exercise should commence as soon as possible.

5.2 SAFETY

Strengths:

- No significant safety incidents occurred during the exercise.
- The use of work gloves proved essential during the practical activities.
- Potential safety issues were addressed proactively and on an ad hoc basis. Participants and instructors were willing to take responsibility and intervene when unsafe situations were observed.
- The regular distribution of small drinking water bottles worked well and contributed to participant welfare.
- Participants had been informed in advance to bring caps and sunscreen, which was particularly beneficial given the weather conditions during the exercise.

Areas for Improvement:

- Two safety-related observations warrant particular attention:
 - A water hose became disconnected during one of the exercises, causing a participant to sustain bruising and become soaked. This highlighted the importance of providing a clear and explicit warning before water is released into a hose or pipeline system.
 - During the filling of the test basin, several participants remained behind the mobile flood barriers while using their phones and were not sufficiently aware of their surroundings. Personnel should not remain within the basin while it is being filled with water. If access is required for operational reasons, this should only take place after an appropriate risk assessment has been performed and suitable control measures have been implemented (e.g. safety lines, waders, or other protective measures). Safety instructions should always be followed, and participants should remain alert during operations.
- A dedicated safety coordinator should be appointed both within the organising working group and during the exercise itself. This individual should monitor safety continuously, provide clear instructions, and intervene when unsafe situations arise.
- Agreements should be made in advance regarding the required personal protective equipment (PPE). In addition, it is recommended that all participants wear work gloves during practical activities.
- Some of the embankment slopes were steep and slippery, making them difficult to traverse safely. To improve safety, designated walking routes should be established and hazardous areas or work zones should be clearly marked or cordoned off where necessary.

- Participants should be reminded continuously to keep the work area tidy and to remove unnecessary materials and equipment during the exercise. Good housekeeping reduces trip hazards, improves safety, and helps prevent the loss or misplacement of equipment..

5.3 FACILITIES (PREPARATION, MATERIALS, SITE ARRANGEMENT, AND COOPERATION BETWEEN WATER AUTHORITIES AND DEFENCE)

Strengths:

- More than sufficient quantities of sandbags and pallets were available throughout the exercise.
- Access to the Defence training area was straightforward and efficient.
- Catering and hydration were well organised, with sufficient food and drinking water available during both exercise days.
- The availability of a mobile crane provided valuable support for handling and transporting materials and equipment.

Areas for Improvement:

- A clear plan should be established in advance for handling wet sandbags after the exercise. Agreements should be made regarding whether the bags are to be stored in cages, stacked on pallets, or disposed of in another manner.
- Tables and chairs were cleared away slightly too early, limiting their availability during the final evaluation and debriefing session. In future exercises, these facilities should remain available until all evaluation activities have been completed.
- For autumn or winter exercises, consideration should be given to erecting a temporary shelter, such as a party tent, to provide participants with a dry and sheltered area for breaks, discussions, and briefings during periods of adverse weather.
- A meeting room on the Defence site should be reserved for working group meetings and exercise preparation activities. This would provide a convenient location for coordination, planning, and operational discussions before and during the exercise.

5.4 ORGANISATION ON SITE AND DEPLOYMENT OF PARTICIPANTS

Strengths:

- The responsibilities within the organising working group were clearly defined.
- All members of the exercise organisation understood their roles and demonstrated a flexible attitude, allowing adjustments to be made between the first and second exercise days where necessary.
- The participants were highly enthusiastic and actively engaged in all exercise activities.

Areas for Improvement:

- On the Monday preceding the exercise, the working group had no opportunity to practise the exercise components themselves. Future planning should include time for instructors and organisers to rehearse the activities beforehand. This would allow practical issues to be identified in advance and enable instructors to focus more fully on guidance during the exercise itself.
- Many participants tended to act independently during the practical exercises. Future exercises should provide more structured instructions, similar to those used in an actual

crisis response situation, and greater attention should be paid to ensuring that participants follow the instructions correctly.

- Instructors should focus on supervising and correcting participants during execution, rather than taking over the task themselves. This ensures that participants gain practical experience and that the intended learning objectives are achieved.
- Leadership and command of participants should be considered an explicit training objective in its own right.
- Each exercise group should be assigned a designated **group leader** responsible for guiding and coordinating the participants.
- Consideration should be given to providing participants within each group with high-visibility vests of a single colour. This would help maintain group cohesion and make it easier to identify participants belonging to a particular exercise team.
- The process of issuing and receiving instructions could be improved. Consideration should be given to having Defence personnel demonstrate and explain command structures and communication procedures at the start of the exercise, including to exercise participants.
- Time should be specifically allocated within the programme for field-based evaluations and participant feedback sessions, allowing observations and lessons learned to be collected immediately after completion of the exercise activities.

5.5 EXERCISE PROGRAMME

5.5.1 MOBILE FLOOD BARRIERS AND SANDBAGGING

Strengths:

- The Sandbagging Handbook proved to be an excellent resource and functioned very effectively for both instructors and participants.
- Participants appreciated the opportunity to observe and compare a variety of mobile flood barrier systems in practice.
- The pallet-based flood barrier systems performed very well during the exercise.
- The pallet systems and the Haawal system were particularly well received because of their simplicity, rapid deployment, and ease of use.

Areas for Improvement:

- Not all systems proved to be compatible when connected to one another. Greater consideration should be given during exercise preparation to which systems can and cannot be effectively combined.
- Future exercises should include additional mobile flood barrier systems and alternative configurations. This would allow participants to gain experience with a broader range of solutions and deployment methods.
- Higher barrier types, capable of retaining water levels exceeding 1 metre, should also be included in future testing programmes. This would provide valuable insights into the deployment, performance, and limitations of larger-scale mobile flood defence systems.

5.5.2 GEOTEXTILE COVERINGS

Strengths:

- Many participants had never previously installed reinforced geotextile coverings. The exercise demonstrated that there is still limited familiarity with both the available reinforcement methods and the practical installation procedures. The opportunity to test a wide range of systems, anchors, pins, and staples was therefore highly valued.
- Participants observed that the properties and intended application of a reinforced geotextile covering are determined primarily by the type of geotextile used. The anchoring method mainly influences ease of installation and the effectiveness of fixation.
- Both Y-pins and U-shaped staples were found to offer specific advantages depending on the application.
- The L-shaped pins and U-shaped staples performed particularly well and were favourably received by participants.

Areas for Improvement:

- Written work instructions are often not consulted during practical field work. The most effective approach is for a designated person to explain the procedure and demonstrate the required actions. Clear instructions supported by illustrations are therefore essential. Participants noted that the current work instructions generally lack sufficient visual guidance.
- For each activity, one person should be assigned to lead the operation and provide instructions, after which a team of approximately five to eight people can carry out the work. This person should also maintain an overview of the activity and coordinate the team.
- Further consideration should be given to determining an optimal design for U-shaped staples, including the appropriate relationship between length, width, and diameter, taking deformation behaviour into account. Ideally, a single staple design would be suitable for multiple reinforcement applications.
- Additional research is recommended into the influence of steel grade on the long-term behaviour of anchors and staples, including deformation, corrosion, residual strength, and ease of removal after prolonged use.
- Especially when installing large reinforced geotextile coverings, careful execution and coordinated supervision are essential. This is particularly true for geogrid systems, where large areas can be installed rapidly. Steep slopes, curved dike alignments, undulating terrain, and uneven surfaces introduce additional challenges. The use of sight lines, step-wise installation procedures, coordinated personnel deployment, and organised distribution of materials can improve efficiency, although installation remains demanding under such conditions.
- Experiences and lessons learned regarding reinforced geotextile coverings should be reviewed jointly with the Emergency Measures Wiki team. Opportunities for further improvement, knowledge sharing, and potentially a dedicated research programme should be explored and made accessible through the Wiki platform.
- A practical toolbox should be developed to support the work instructions, covering:
 - The various reinforcement methods available and the situations for which they are most suitable;
 - Different types of staples, pins, and anchoring systems, including their effectiveness and safety characteristics;
 - Key considerations, including recommended practices and common pitfalls;

- Explanations supported by a substantially larger number of illustrations and practical examples.
- Further investigation is recommended into the most effective staple pullers and hook configurations. During the exercise, attention focused primarily on the puller itself, whereas the design of the hook proved equally important because it determines whether staples can be gripped effectively. Due to its large and bulky hook, the small red stake puller was found to be ineffective. The black and orange pullers performed well, as did the pickaxe. Cost considerations should also be taken into account, as staple pullers range from approximately €50 to €250. Mechanical extraction methods should also be evaluated.
- Installation is only one part of the process; removal and clean-up are equally important. Future training exercises should explicitly include retrieval and decommissioning activities to ensure participants gain experience with the full life cycle of reinforced geotextile coverings.

5.5.3 SAND BOIL RING-DIKING

Strengths:

- The exercise proved to be highly valuable, particularly when combined with the basic sandbagging training. Participants gained practical experience in both constructing sandbag structures and mitigating sand boils.
- The elevated water tank used to generate the artificial sand boil functioned well and provided a realistic demonstration of seepage conditions associated with piping.
- Having one participant read the work instruction aloud while the others carried out the activities proved to be an effective way of ensuring that the procedure was followed correctly.
- There was sufficient time to discuss and evaluate innovative mitigation measures, such as the sand boil cap, sand boil mattress, and other alternative solutions.

Areas for Improvement:

- Communication was occasionally difficult because the sand boil exercise area was located at a considerable distance from the test basin and the other exercise components. Future exercises could benefit from improved communication facilities or a more compact site layout.
- Future exercises should include the construction of sandbag ring dikes in a water-filled ditch or similar realistic environment, for example in a military engineering trench, to provide additional practical experience under more representative field conditions.
- Future exercises should preferably be conducted using either real or more realistic artificial sediment-carrying sand boils. This would not only improve the realism of the training but would also provide the opportunity to test and evaluate innovative mitigation measures under representative hydraulic conditions.

5.6 COMMUNICATION AND DOCUMENTATION/DISSEMINATION OF FINDINGS

Strengths:

- Sufficient time was allocated for communication and discussion throughout the exercise.
- The use of a dedicated messaging group for participants attending each exercise day proved to be an effective communication tool.

Areas for Improvement:

- Greater clarity should be established at an earlier stage regarding the objectives of the exercise and the intended target audience.
- A structured evaluation session was missing at the end of the first exercise day. Since the participants attending the first and second days were not the same, valuable feedback from the first-day participants could not be systematically captured. In addition, by the time the evaluation took place on the second day, not all observations from the first day were still readily available to the instructors. It is therefore recommended to schedule a dedicated evaluation session at the end of each exercise day.
- Communication and dissemination of exercise outcomes could be expanded through platforms such as LinkedIn and the CTW app.
- A dedicated person should be appointed to document the exercise through photographs and other visual material. The focus should not only be on producing attractive images for communication purposes, but also on systematically documenting the performance of tested systems, including observed shortcomings and failure mechanisms. Such visual documentation forms an important basis for the development of high-quality work instructions. The observers involved in the exercise may be well suited to take a leading role in this activity.
- Consideration could also be given to involving a photographer equipped with professional camera equipment. This would facilitate the production of high-quality communication material as well as valuable overview images for reporting and training purposes.

5.7 IDEAS FOR FUTURE EXERCISES

- Test additional types of mobile flood barriers.
- Evaluate competing products that fulfil a similar function, for example:
 - Water-Gate as an alternative to the Buitink Flexible Flood Barrier (BFW);
 - NoFloods Easy Wall as an alternative to the Waterschot system.
- The emergency flood protection measures tested during this exercise had relatively limited crest heights. Such heights are of limited applicability in large river systems. Future exercises should therefore include higher emergency flood barriers.
- Consider testing the use of industrial pallets as an alternative to Europallets. Industrial pallets are generally higher and more durable than Europallets. However, they are available in smaller quantities and are less standardised, with several different variants in circulation. Although technically suitable for emergency flood barrier construction, they may be less attractive from a logistical perspective, as they are not supported by a standardised exchange and pooling system comparable to the EPAL/EUR pallet network. Europallets, by contrast, are widely available in the transport, industrial, and construction sectors and can typically be obtained quickly during emergencies.
- Investigate the impact of floating debris on the stability and performance of mobile flood barriers.
- Include practical exercises involving the use of straw bales as temporary flood barriers.
- Practise the construction of sandbag ring dikes under water, for example in a water-filled ditch or similar environment.
- Organise a train-the-trainer course focusing on instructional skills. Such training should address the knowledge and competencies required to direct and supervise others effectively without becoming directly involved in the practical work or intervening unnecessarily. This would strengthen leadership and command capabilities during emergency response operations