https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019


Natural Hazards and Earth System Sciences
Discussions

# Sandbagging versus Sandbag Replacement Systems: Costs, Time, Helpers, Logistics

Lena Lankenau[1], Bärbel Koppe[1]

[1]Institute for Hydraulic and Coastal Engineering, Hochschule Bremen – City University of Applied Sciences, Bremen, 28199, Germany

*Correspondence to*: Lena Lankenau (lena.lankenau@hs-bremen.de)

**Abstract.** The classic aid in operative flood defence is the sandbag. Over the past few decades, though, so-called sandbag replacement systems (SBRS) have also been available for flood fighting. The use of sandbags is time-consuming as well as highly intensive in terms of materials and personnel. In contrast, the use of SBRS entails higher investment costs. However, SBRS are reusable and require lower costs for helpers and logistics, so that the higher investment costs are offset by repeated use. In fictitious but realistic scenarios, the use of sandbags and sandbag replacement systems is compared in order to enable a comparison of requirements such as deployment costs, time and helpers. Three different linear SBRS were compared to a 1.0-metre high and 100-metre long sandbag dam. Furthermore, the dyke defence measures load drain and ring dyke were compared with the comparable SBRS available on the market. All three SBRS clearly show time saving and logistical advantages. Under the assumed conditions, the higher investment costs of the SBRS are already amortised with one subsequent reuse.

## 1 Introduction

The classical means of mobile flood protection is the sandbag. In addition, so-called sandbag replacement systems (SBRS) have been available for flood protection for some time now. SBRS are divided into tube, basin, flap, trestle, dam or panel systems or bulk elements which counteract the effects of flooding either by their weight and volume due to the use of water, sand or concrete or by their geometry in combination with hydrostatic water pressure. In Germany during the Elbe flood in 2013, SBRS were only used in isolated cases (cf. AQUARIWA, 2019, Mobildeich, 2019), despite the fact that the use of sandbagging for operational flood defence is very time, materials and labour intensive. The great advantage of sandbagging lies in flexibility and many years of practical experience. In contrast, SBRS can be used to make operational flood defence much more efficient. Their use, though, initially requires higher investment costs. However, the lower expenditure on helpers and logistics means that these higher investment costs can be offset through a reuse. Nevertheless, SBRS are still rarely used in operational flood defence. There are many reasons for this, the main ones being limited confidence in their functionality, especially when the constructions are directly exposed to the rising flood levels as it is the case for the linear SBRS, and hurdles to their procurement — especially their financing. An evaluation of the functionality of different SBRS

https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019


Natural Hazards and Earth System Sciences
Open Access
Discussions

on the basis of test setups was presented in Lankenau et al. (2019). The present article compares the use of sandbags and sandbag replacement systems in fictitious realistic scenarios in order to enable a comparison of the costs surrounding system deployment, the time involved and helpers. The comparison serves to further clarify the practical suitability of SBRS and, in addition to the acquisition costs, takes into account the costs of installing and dismantling the systems as well as the costs of logistics.

There are relatively few publications on comparative studies of sandbagging and SBRS. Within the scope of test setups in the test basin of the U.S. Army Corps of Engineers (USACE), one sandbag dam as well as two sand-filled container systems and one trestle system were investigated (Pinkard et al., 2007). In addition to the time spent on system installation and dismantling, the operating costs for a system set-up with a length of around 305 metres and a height of around 0.91 metres were also estimated. However, logistical aspects were not taken into account, and it was assumed that labour on the construction of the sandbag dam would be on a free and voluntary basis. In addition, the sandbag requirement estimated in the study differs from the usual approaches in Germany, as the sandbag dam in the U.S. is constructed on a broader basis.

In a report published by the U.K. Environment Agency (EA) in 2013, the relevance of life cycle costs when using SBRS is highlighted (Ogunyoye et al., 2011). In addition to the acquisition costs, these include costs for maintenance and repair of the systems, costs for employees and their training as well as for the performance of field exercises and costs for storage and transport of the systems. The benefit of an SBRS, on the other hand, also results from the costs of damage that can be prevented during its service life, whereby a properly functioning system is assumed. An exemplary calculation of the life cycle costs of an SBRS is not carried out in the report. Only the acquisition costs of SBRS, partly including the training of helpers by the manufacturers, for a 100-metre long system with a protection height of about 1 metre in the four categories examined — tubes, containers, freestanding barriers and frame barriers — are mentioned.

In a Canadian study (Biggar et al., 1998), in which the authors assessed the suitability of SBRS as an alternative to sandbags primarily on the basis of the literature and manufacturers' brochures as well as theoretical considerations and stability calculations, four different system types were examined. These include water- or air-filled tube systems, gabion-like systems filled with sand or soil, dam beams and motorway crash barriers. Besides the assessment of the suitability of the systems, the factors to be considered for the cost calculation of SBRS are named, but no comparative calculations are carried out. The stated costs refer to manufacturer's prices for a system with a protection length of 30 metres and a protection height of about 1 metre. The additional financial resources to be considered include costs for storage, assembly and dismantling of the systems as well as for training the helpers. Moreover, the durability of the systems must also be taken into account, as a long service life has a positive effect on the number of times a system can be reused.

None of the examples mentioned in the literature examined the costs of securing saturated dykes on selective points where there is considerable seepage or over a large area. In the present study, in addition to the temporary flood protection dam, appropriate dyke defence measures for operational flood defence are also considered. The calculated operational costs always depend on the underlying system model or dimensions of the sandbag system and other factors taken into account in the cost calculation: this necessarily calls for a certain degree of simplification. This aspect results in deviations in the

Natural Hazards and Earth System Sciences Discussions

findings of the above-mentioned studies by Pinkard et al. (2007) and Ogunyoye et al. (2011) and the present study. In order to shed more light on the efficiency of SBRS, in addition to the costs involved, the expenditure on time and logistics as well as the helper hours required to set up or dismantle the sandbag system and SBRS are compared.

## 2 Description of scenarios

The costs as well as time, helper and logistics requirements for the installation and dismantling of sandbag systems and SBRS were determined for three different cases:

1. Temporary flood dam
2. Load drain in the case of a saturated dyke over an extensive area
3. Ring dyke for reinforcement against heavy punctual exit of seepage on the inner embankment of the dyke

In case 1, systems directly exposed to flooding are considered, while cases 2 and 3 refer to systems used to stabilise the landside embankment of a break-prone dyke. The latter systems are generally exposed to lower loads as they are not subjected to the direct influence of high hydrostatic pressures or the dynamic impact caused by waves and flotsam. They are therefore less endangered in their functionality. In case 1, in addition to the sandbag dam, three different SBRS types (basin, tube and trestle) were considered. One manufacturer of each system type was selected. In cases 2 and 3, the only suitable SBRS on the market is that provided by FLUTSCHUTZ. When determining the costs for the installation and dismantling of the systems, in addition to the acquisition costs, the costs for logistics and helpers were taken into account as well as the costs of materials and the disposal of sand and sandbags.

In the case of the temporary flood dam, a protection length of 100 metres and a protection height of 1.0 metre were assumed. The height of the sandbag dam was assumed to be 1.0 metre, as the dam can theoretically protect against water levels up to its full height. The SBRS AQUARIWA (basin system) with a protection height of 1.0 metre and a freeboard of 0.5 metre, the FLUTSCHUTZ-Doppelkammerschlauch (DKS - double chamber tube system) with a protection height of 0.6 metre and a freeboard of 0.3 metre as well as Aqua defence (trestle system) with a maximum protection height of 1.3 metres were compared. The differences in the protection heights are system specific and cannot therefore be avoided. Practical tests (Massolle et al., 2018) have shown that the FLUTSCHUTZ-DKS can dam a water head up to a height of one metre, whereby, due to the lateral pressure exerted when filling the test basin, performance can be increased above the system height of 0.9 metre specified by the manufacturer. In case 2, the sandbag load drain was compared with a FLUTSCHUTZ-Auflast (load drain), and in case 3, the sandbag ring dam was compared with a FLUTSCHUTZ-Quellkade (ring dam). The systems evaluated in cases 1 (temporary flood dam), 2 (load drain) and 3 (ring dam) are shown in Figure 1.

The cost calculation assumed technical assistance provided by the emergency services of the German Federal Agency for Technical Relief (THW). Such federal assistance takes place within the framework of inter-agency cooperation and is generally requested by the responsible state authorities during extreme flood events. For the resources made available — primarily vehicles, pumps and hoses — as well as THW helpers, the costs were calculated on the basis of the *Verordnung über die Durchführung und Abrechnung von Hilfeleistungen des Technischen Hilfswerks* (Ordinance on the Implementation

https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019



and Invoicing of Assistance Provided by the Technical Relief Agency), in accordance with the Annex to Section 4 (3) of the THW Invoicing Ordinance (THW-V, 2019). During a flood, the German Federal Armed Forces and other relief organisations such as fire brigades and the police can be deployed in addition to THW and emergency services. Depending on the organisation, the individual costs may vary: this, however, has not been taken into consideration for the present cost estimate.

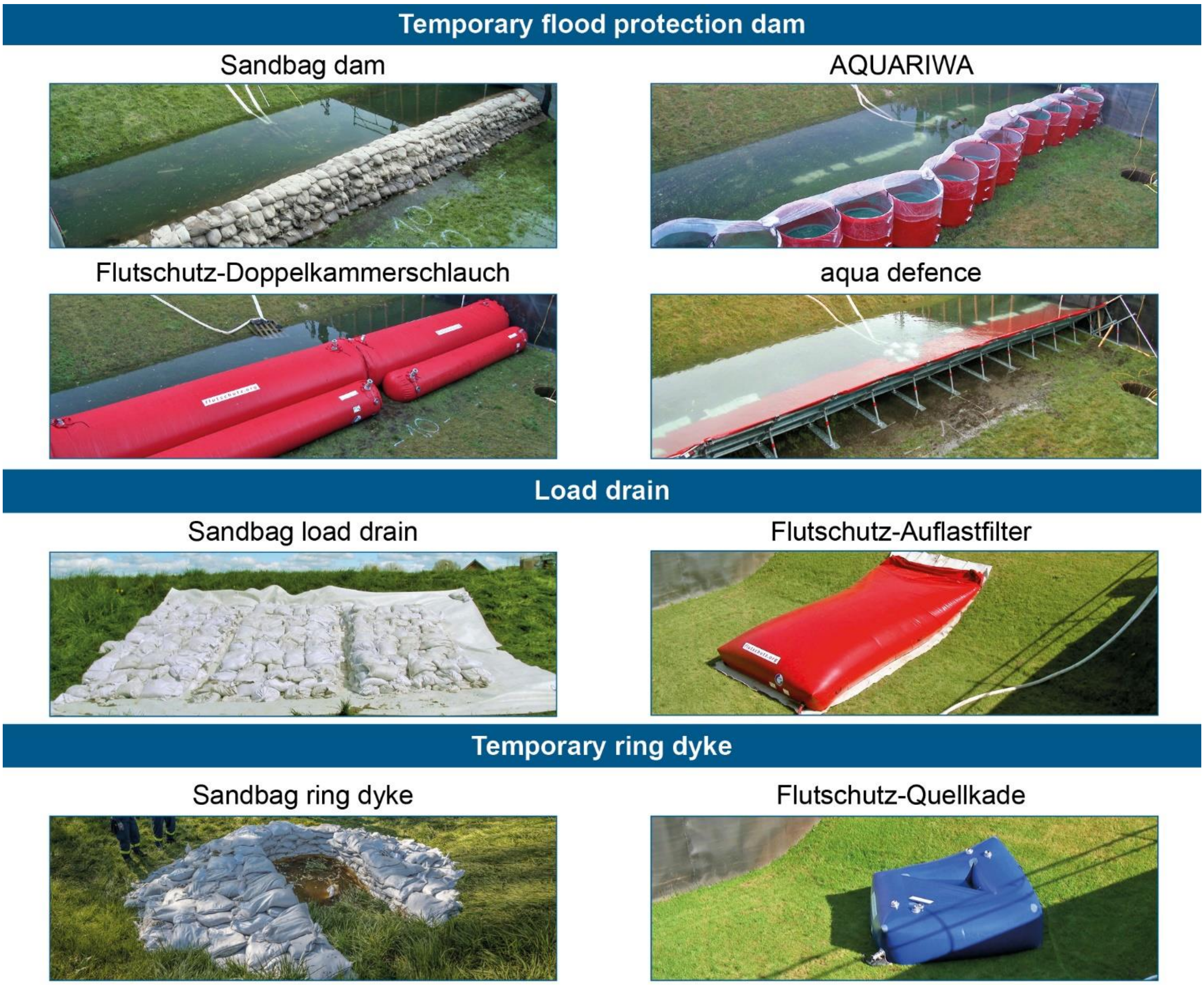


**Figure 1. Systems considered within the scope of the comparison - sandbag system and SBRS.**

The requirement for sandbags and sand as well as the labour needed for filling and laying the sandbags are based on empirical values supplied by THW (THW, 2017). The labour time needed for the installation of the SBRS was estimated on the basis of the authors' empirical values (Massolle et al, 2018). In the case of water-filled systems in particular, the time required to dismantle an SBRS is less than that required for the installation, as the systems can be allowed to drain empty at the same time without the need for pumps. For the water-filled systems, 20% of the time required for installation was therefore estimated for dismantling. In practice, it should be noted that these estimates depend on the conditions and accessibility on site and, moreover, that dismantling is generally not financed by the federal authorities and therefore also not by THW. With the end of the flood hazard — and thus the disaster event — assistance on the part of the federal authorities is terminated: the municipalities and administrative districts become responsible for the measures taken. Owing to a lack of helpers, this can often lead to considerable problems following major flood events.

The following times were assumed for cleaning the systems:

- FLUTSCHUTZ-DKS, length 10 metres: 1.5 hours
- Aqua defence, length 1.22 metres: 5 minutes
- AQUARIWA, length 1.5 metres: 5 minutes
- FLUTSCHUTZ load drain: 1 hour
- FLUTSCHUTZ ring dam: 1 hour

The sandbag requirement for SBRS with upstream skirt (AQUARIWA, aqua defence) is 4 sandbags per linear metre. The basic helper requirement is 10 persons per sandbag dam and 2.5 persons per SBRS, whereby foremen (group leaders) are taken into account. In practice, the systems should be set up by a larger team of helpers, but fictitious helper teams with a minimum number of helpers were assumed for the calculation. Per helper hour, 22.00 euro is estimated as the average loss of remuneration to be reimbursed (THW-V, 2019). The average weight of a sandbag is 12 kg (THW, 2017). A requirement of 15 kg sand per sandbag was assumed in order to take overfilling and sand losses into account. On the other hand, no reserve margin for defective sandbags etc. is taken into account, but is considered to be included in the excess demand for sand. A sandbag purchase price of 0.20 euro takes into account the slight price increase to be expected during a flood event. No voluntary or private-sector assistance is taken into account. However, the participation of other volunteers can significantly reduce the costs for the construction of a sandbag dam, as the helper costs make up the largest cost factor. It should be taken into account, though, that the resulting costs are usually borne by the volunteers themselves — the costs are therefore only transferred. The calculation also does not include costs for travel/ food/accommodation/ sanitary needs of the volunteers, upper command, long transport routes/ alternative means of transport in case of poor access, other material requirements (shovels etc. for filling the sandbags), the transport of sand/ supplementary materials as well as storage of SBRS/ sandbags/ shovels etc. and necessary repairs to the SBRS.

In principle, the selected SBRS are reusable. Only the AQUARIWA system needs to have the inner bags replaced after using the system; the price per bag is low and was therefore neglected in the calculation. It is assumed that with smaller quantities of SBRS, storage on site, e.g. by local dyke management units (*Deichverbände*), is possible without difficulty. Only in the case of larger stocks will higher demands be placed on storage requirements.

Just like SBRS, sandbags must also be stored. They have a significantly lower shelf life than SBRS. If stored properly, filled sandbags have a maximum shelf life of 5 years. If unfilled, they can be stored for up to 10 years. However, it should be noted that the shelf life of filled sandbags may be severely limited if they are stored under poor conditions. When stored outdoors,

https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019

Natural Hazards and Earth System Sciences Discussions
Open Access EGU

after only a few months sandbags can be so decomposed that they are no longer fit for use. In the case of SBRS, the guarantee period specified by the manufacturer must be compared to the actual shelf life. Inquiries to manufacturers have shown that not all producers give a guarantee or that the guarantee often only amounts to a few years. When interviewed, however, some manufacturers stated that the service life of demonstration models reached 10 years and more. Considering the materials used in the production of the SBRS, such as tarpaulin fabric, galvanised steel or fibreglass-reinforced plastic, it can certainly be assumed that an SBRS can have a service life of 10 years and more. In view of this, the calculation equates the repair requirements of SBRS with the inspection and renewal requirements of stored sandbags.

The need to regularly test the construction of SBRS is likewise equated with the requirement to carry out flood protection exercises when relying on the use of sandbag systems. It was also assumed that the sandbag systems, like the SBRS, should be continuously monitored during a flood event in order to monitor their functionality and to check the systems for damage caused by mechanical influences or vandalism. If deemed appropriate, the SBRS should be inspected at shorter intervals than sandbag systems. However, the additional requirement for labour is comparatively low and was therefore neglected.

## 3 Costs of deployment, time involved, helpers and logistics

### 3.1 Costs of deployment

The overview of the total cost of installing and dismantling the flood protection systems shows that under the assumed conditions the costs resulting from the one-off use of the SBRS are around 30% - 50% higher than for a comparable sandbag system. However, since the SBRS, in contrast to the sandbag systems, are largely reusable, the higher investment costs of the SBRS are already amortized during their second application. Table 1 shows the cost estimates for the temporary flood dams (case 1) and Table 2 for the load drain (case 2) and the ring dam (case 3). In each case, the costs incurred for installing the systems exceed the costs for their dismantling. Whereas the costs for dismantling the sandbag dam amount to approx. 70% of the costs of installation, in the case of SBRS the dismantling costs are in the low single-digit percentage range compared to their installation.

**Table 1. Comparison of the costs for installation and dismantling of sandbag systems and SBRS – Temporary flood dam, protection length 100 metres (case 1).**

| | **Sandbag dam** | **FLUTSCHUTZ -DKS** | **Aqua defence** | **AQUARIWA** |
|---|---|---|---|---|
| Helpers, incl. lower command | 10 | 2.5 | 2.5 | 2.5 |
| Sandbag requirement [40 x 60 cm, empty] | 16 500 | - | 400 | 400 |
| **Installation** | | | | |
| Time per dam [h] | 61.88 | 7.50 | 8.48 | 10.71 |
| Costs of helpers [€] | 13 612.50 | 412.50 | 466.40 | 523.05 |
| Costs of materials, incl. replacements [€] | 5 898.75 | 42 930.33 | 47 400.15 | 51 758.87 |

Natural Hazards and Earth System Sciences
Discussions

| | Sandbag dam | FLUTSCHUTZ -DKS | Aqua defence | AQUARIWA |
|---|---|---|---|---|
| Costs of trucks, incl. fuel [€] | 641.47 | 35.06 | 37.56 | 28.02 |
| Total installation costs without materials [€] | 14 253.97 | 447.56 | 503.96 | 617.07 |
| 3% sundry costs [€], based on total operating costs: 15 € - 150 € | 150.00 | 15.00 | 15.12 | 18.51 |
| Total costs of installation [€] | 20 302.72 | 43 392.89 | 47 919.23 | 52 416.95 |
| **Dismantling** | | | | |
| Time per dam [h] | 20.63 | 16.55 | 12.96 | 9.10 |
| Costs of helpers [€] | 4 537.50 | 907.50 | 712.8 | 390.61 |
| Costs of materials [€] | 8 250.00 | - | 200.00 | 200.00 |
| Costs of trucks, incl. fuel [€] | 641.47 | 35.06 | 37.56 | 28.02 |
| Total dismantling costs without materials [€] | 5 178.97 | 942.56 | 750.36 | 418.63 |
| 3% sundry costs [€] based on total operating costs: 15 € - 150 € | 150.00 | 28.28 | 22.51 | 15.00 |
| Total costs of dismantling [€] | 13 578.97 | 970.83 | 972.87 | 633.63 |
| **Installation and dismantling** | | | | |
| Total costs [€] | 33 881.69 | 44 363.72 | 48 892.10 | 53 050.58 |

**Table 2. Comparison of the costs for the installation and dismantling of sandbag and sandbag replacement systems load drain (case 2) and ring dam (case 3).**

| | Load drain | | Ring dam | |
|---|---|---|---|---|
| | **Sandbag** | **FLUTSCHUTZ** | **Sandbag** | **FLUTSCHUTZ** |
| Helpers, incl. lower command | 10 | 2.5 | 10 | 2.5 |
| Sandbag requirement [40 x 60 cm, empty] | 980 | - | 900 | - |
| **Installation** | | | | |
| Time per element [h] | 4.90 | 0.50 | 4.50 | 0.50 |
| Costs of helpers [€] | 1 078.00 | 27.50 | 990.00 | 27.50 |
| Costs of materials, incl. replacements [€] | 350.53 | 3 046.28 | 321.75 | 3 726.01 |
| Costs of trucks, incl. fuel [€] | 41.31 | 6.93 | 38.18 | 6.93 |
| Total costs without materials [€] | 1 119.31 | 34.43 | 1.028.18 | 34.34 |
| 3% sundry costs [€] based on total operating costs: 15 € - 150 € | 33.58 | 15.00 | 30.85 | 15.00 |
| Total costs of installation [€] | 1 503.24 | 3 118.21 | 1 380.78 | 3 748.51 |
| **Dismantling** | | | | |
| Time per dam [h] | 2.45 | 1.10 | 2.25 | 1.10 |
| Costs of helpers [€] | 539.00 | 60.50 | 495.00 | 60.50 |
| Costs of materials [€] | 490.00 | - | 450.00 | - |

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

| | **Load drain** | | **Ring dam** | |
|---|---|---|---|---|
| | **Sandbag** | **FLUTSCHUTZ** | **Sandbag** | **FLUTSCHUTZ** |
| Costs of trucks, incl. fuel [€] | 41.31 | 6.93 | 38.18 | 6.93 |
| Total operating costs without materials [€] | 580.31 | 67.43 | 533.18 | 67.43 |
| 3% sundry costs [€]based on total operating costs: 15 € - 150 € | 17.41 | 15.00 | 16.00 | 15.00 |
| Total costs of dismantling [€] | 1 087.72 | 82.43 | 999.18 | 82.43 |
| **Installation and dismantling** | | | | |
| Total costs [€] | 2 590.96 | 3 200.63 | 2 379.96 | 3 880.36 |

In the case of sandbag systems, both sand and sandbags must first be procured. These are usually only stocked in small quantities, and in the event of procurement during a flood event, it must be expected that prices will rise sharply. The sandbags must then be filled and laid with a great deal of time and effort. These aspects must be weighed against the investment costs for the respective SBRS, which, however, can be used several times. In order to replace damaged systems after use, an average new procurement requirement of 5% is assumed within the system service life. The sandbags required to weigh down and seal the upstream skirt of an SBRS are comparatively insignificant. The logistics costs for installation and dismantling are quite the same owing to the equally long travel distance: for the sandbag systems they are higher compared to SBRS, owing to the greater bulk. Basically, the logistics costs for all systems are comparatively low, which is also due to the comparatively low costs for the use of THW vehicles. When dismantling, the costs for the sandbag systems are higher than for the SBRS, owing to the extra need for helpers and the disposal of the sandbags. However, if it is possible to deploy heavy equipment for the dismantling of a sandbag dam, these costs can be lower than estimated in the present calculation because of the lower requirement for helpers and the shorter time involved. Overall, the largest cost items for the sandbag systems are the costs for the deployment of helpers and the procurement of materials, and for the SBRS the procurement of the systems. If, in addition to the costs for installation, the costs for dismantling are also taken into account, from a financial point of view and under the assumed conditions, the purchase of SBRS makes sense as they are amortised already during the second deployment. The investment costs did not include a quantity discount for the purchase of larger system lengths.

From a financial point of view, the use of the SBRS as a temporary flood dam is particularly worthwhile for protection against higher flood levels. If the protective height is reduced, the installation costs for the temporary sandbag dam decrease owing to the lower sandbag requirement. SBRS, on the other hand, can rarely be flexibly adjusted in height, so that with lower system heights, the cost amortization in comparison to sandbag dams of low height only takes place after a number of deployments. For example, the costs for constructing a sandbag dam with a height of 0.50 metre and a length of 100 m are only approx. 8,090 euro for installation, approx. 5,352 euro for dismantling and approx. 13,442 euro for installation and dismantling. If an SBRS is offered in different system heights, savings can also be expected if lower system heights are used, but these are less significant. It should also be noted that the procurement costs of SBRS supplied by other manufacturers may differ from those of the manufacturers considered here.

Natural Hazards and Earth System Sciences Discussions

If there should be insufficient water available from natural sources (e.g. river water) in the immediate vicinity of where water-filled systems are to be installed, the costs for the water filling are comparatively low (approx. 400 euro FLUTSCHUTZ-DKS and 150 euro AQUARIWA). If tank trucks have to be used, however, the logistical effort increases. Notwithstanding, the time, material and helper advantages of SBRS remain in all of the cases considered here.

The calculations did not take into account the costs for upper command or travel, meals, overnight accommodation and sanitary requirements of the helpers. For upper command, i.e. the disaster control management, technical incident command and platoon, 5 euro per helper and day can be assumed. If one furthermore estimates 25 euro per day for overnight accommodation, food and sanitary needs of the helpers, then with a helper day of 12 hours per sandbag system in cases 1, 2 and 3 approx. 6 %, and per SBRS approx. < 1 % more costs are incurred.

### 3.2 Time, helper and logistics requirements

For cases 1, 2 and 3, the estimated time, helper and logistics requirements are shown in Table 3 and Table 4. The time, materials and helper advantages of the SBRS are clearly visible. In case 1, the use of SBRS requires approx. 25 % - 30 % of the time, approx. 5 % - 7 % of the helper hours and approx. 5 % of the trucks compared to the sandbag dam. If more helpers or trucks are used, the respective proportions shift, but the total effort remains the same. In case 2 and case 3, approx. 40 % of the time and approx. 6 % of the helper hours are required when using SBRS. The logistics data in case 2 and case 3 were rounded up to fully loaded trucks. Eight FLUTSCHUTZ load drains or ring dams can be transported per truck, so that when using these SBRS there is a need for only approx. 8 % - 9 % of the trucks required for sandbag systems.

When sandbag systems are used, poor access — and thus the need for sandbags being passed on over longer distances by means of a sandbag chain — may result in a significant additional need for helpers or the use of alternative means of transport such as helicopters or boats. This can also considerably increase the time required for transport as well as the costs incurred. The possible scenarios are manifold and could therefore not be considered in detail.

**Table 3. Comparison of time, helpers and logistics requirements for the installation and dismantling of sandbag and sandbag replacement systems - Temporary flood dam (Case 1).**

| | **Sandbag dam** | **FLUTSCHUTZ-DKS** | **Aqua defence** | **AQUARIWA** |
|---|---|---|---|---|
| Helpers, incl. lower command | 10 | 2.5 | 2.5 | 2.5 |
| Trucks | 26 | 2 | 2 | 1 |
| **Installation** | | | | |
| Time materials [h] | 41.25 | - | 2.00 | 2.00 |
| Time logistics [h] | 1.00 | 1.00 | 1.00 | 1.00 |
| Time installation [h] | 20.63 | 7.50 | 6.48 | 8.71 |
| Total time, incl. logistics [h] | 62.88 | 8.50 | 9.48 | 11.71 |
| Total helper hours [h] | 618.75 | 18.75 | 21.20 | 26.78 |

https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019

Natural Hazards and Earth System Sciences
Discussions

| | Sandbag dam | FLUTSCHUTZ -DKS | Aqua defence | AQUARIWA |
|---|---|---|---|---|
| **Dismantling** | | | | |
| Time materials [h] | - | - | - | - |
| Time logistics | 1.00 | 1.00 | 1.00 | 1.00 |
| Time dismantling, incl. cleaning SBRS [h] | 20.63 | 16.50 | 12.96 | 7.10 |
| Total time, incl. logistics [h] | 21.63 | 17.50 | 13.96 | 8.10 |
| Total helper hours [h] | 206.25 | 41.25 | 32.40 | 17.76 |
| **Installation and dismantling** | | | | |
| Total time, incl. logistics [h] | 84.50 | 26.00 | 23.44 | 19.81 |
| Total helper hours [h] | 825.00 | 60.00 | 53.60 | 44.53 |

**Table 4. Comparison of time, helpers and logistics requirements for the installation and dismantling of sandbag and sandbag replacement systems – load drain (case 2) and ring dam (case 3).**

| | Load drain | | Ring dam | |
|---|---|---|---|---|
| | **Sandbag** | **FLUTSCHUTZ** | **Sandbag** | **FLUTSCHUTZ** |
| Helpers, incl. lower command | 10 | 2.5 | 10 | 2.5 |
| Trucks | 2 | 1 | 2 | 1 |
| **Installation** | | | | |
| Time materials [h] | 2.45 | - | 2.25 | - |
| Time logistics [h] | 1.00 | 1.00 | 1.00 | 1.00 |
| Time installation [h] | 2.45 | 0.50 | 2.25 | 0.50 |
| Total time, incl. logistics [h] | 5.90 | 1.50 | 5.50 | 1.50 |
| Total helper hours [h] | 49.00 | 1.25 | 45.00 | 1.25 |
| **Dismantling** | | | | |
| Time materials [h] | - | - | - | - |
| Time logistics | 1.00 | 1.00 | 1.00 | 1.00 |
| Time dismantling, incl. cleaning SBRS [h] | 2.45 | 1.10 | 2.25 | 1.10 |
| Total time incl. logistics [h] | 3.45 | 2.10 | 3.25 | 2.10 |
| Total helper hours [h] | 24.50 | 2.75 | 22.50 | 2.75 |
| **Installation and dismantling** | | | | |
| Total time, incl. logistics [h] | 9.35 | 3.60 | 8.75 | 3.60 |
| Total helper hours [h] | 73.50 | 4.00 | 67.50 | 4.00 |

## 4 Conclusions

The authors' determination of the operational costs was carried out for specific scenarios and with several simplifications, but nevertheless allows an approximate estimate of the operational costs of using sandbags and sandbag replacement systems under realistic conditions. With regard to amortization of the higher acquisition costs of SBRS, the number of times a system can be used within its service life plays a decisive role, since the acquisition costs of the investigated systems are amortized during their subsequent reuse. Irrespective of this, owing to their time-, material- and personnel-saving characteristics SBRS offer the potential to make operational flood protection considerably more efficient than a system based solely on sandbagging. In particular, the time saved during operation must be taken into account here, which may even be crucial to providing protection in the first place.

No matter whether SBRS find increasing application in future, sandbags will continue to play an important role in flood defence owing to their simple application and high flexibility — even if, for example, they are only used to close gaps for which prefabricated systems of a certain length are not suitable.

In addition to further technical examination of the functionality of SBRS in realistic tests and subsequent certification, in order to promote the use of SBRS in operational flood protection and for the protection of populations, it is necessary to overcome the financial hurdles to their procurement. In particular, it is necessary to provide financial support to the municipal authorities responsible for the purchase of the systems. This could, for example, entail eliminating the difference in the financing of the contingency costs of protection systems and the costs of using the systems, because in the event of a disaster event the costs for operational flood defence are generally borne by the federal states or the federal authorities, but the costs for maintaining a minimum quantity of protection systems are borne by the municipalities. Whereby sandbags and the filling material can still be procured at very short notice in the event of flooding, it is not so easy to procure SBRS that may still have to be produced. However, since SBRS can be transported with comparatively low logistical effort, a more centralised storage system is conceivable, so that in the event of flooding, the systems can also be transported from more distant regions that are not immediately affected by the flood. This would be in the interest of a cross-municipal and therefore cost-effective acquisition.

## Author contribution

Conceptualisation: B.K.; Methodology: L.L.; Formal Analysis: L.L.; Writing — original draft preparation: L.L.; Writing — review and editing: B.K. and L.L.; Visualisation: L.L..; Supervision: B.K.; Project administration: B.K.; Funding acquisition: B.K.

## Conflicts of interest

The authors declare that they have no conflict of interest.

## Acknowledgements

We would like to thank the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the THW Foundation for their financial support of the project 'Adaptation of flood protection training and dyke defence to the

https://doi.org/10.5194/nhess-2019-165
Preprint. Discussion started: 27 May 2019



challenges of climate change at the THW Training Centre Hoya' (HWS-Bildung, duration 2016 - 2018), funded within the framework of the German Strategy for Adaptation to Climate Change, in the course of which this publication was prepared.

## References

AQUARIWA Homepage: http://www.AQUARIWA.de/die-einsaetze/AQUARIWA-in-gartow-juni-2013/#die-einsaetze/AQUARIWA-in-gartow-juni-2013/, last access: 20 May 2019.

Biggar, K. and Masala, S.: Alternatives to sandbags for temporary flood protection, Alberta Transportation and Utilities Disaster Services Branch and Emergency Preparedness Canada, Edmonton, AB and Ottawa, ON, Canada, 1998.

Hamburger Abendblatt Homepage: Teure Entsorgung: Sandsäcke der Flut sind Sondermüll, published on 26 June 2013: https://www.abendblatt.de/region/article117453750/Teure-Entsorgung-Sandsaecke-der-Flut-sind-Sondermuell.html, last access: 20 May 2019.

Lankenau, L., Massolle, C., Koppe, B., Krull, V.: Sandbag Replacement Systems - Stability, Functionality and Handling, Nat. Haz., 2019.

Massolle, C., Lankenau, L., Koppe, B.: Emergency Flood Control: Practice-Oriented Test Series for the Use of Sandbag Replacement Systems, Geosciences, 8, 482, https://doi.org/10.3390/geosciences8120482, 2018.

Mobildeich Homepage: https://www.mobildeich.de/de/referenz.php#filme, last access: 20 May 2019.

Ogunyoye, F.; Stevens, R.; Underwood, S.: Delivering benefits through evidence. Temporary and Demountable Flood Protection Guide, Environment Agency, Bristol, 2011.

Pinkard, F., Pratt, T., Ward, D., Holmes, T., Kelley, J., Lee, L. T., Sills, G., Smith, E., Taylor, P. A., Torres, N., Wakeley, L., Wibowo, J.: Flood-Fighting Structures Demonstration and Evaluation Program: Laboratory and Field Testing in Vicksburg, Mississippi, U.S. Army Corps of Engineers, Washington, 2007.

Technisches Hilfswerk (THW): THW-Taschenkarte Hochwasserschutz und Deichverteidigung, Stand 02.08.2017, unveröffentlicht; THW-Ausbildungszentrum Hoya, 2017.

Verordnung über die Durchführung und Abrechnung von Hilfeleistungen des Technischen Hilfswerks, Gesetze-im-Internet Homepage: http://www.gesetze-im-internet.de/thw-abrv/anlage.html, last access: 20 May 2019.