# Compartmentalisation of the storage basin system

Compartmentalisation is defined as splitting up an area into smaller units or compartments. In most cases, dike rings are compartmentalised or split up into smaller dike rings, while the land is usually left intact.


1. INTRODUCTION
2. RELATED TOPICS AND DELTA FACTS
3. MULTILAYER SAFETY STRATEGY
4. SCHEMATIC
5. TECHNICAL OPERATION
6. POSITIONING
7. GOVERNANCE
8. COSTS AND BENEFITS
9. LESSONS LEARNED AND ON-GOING STUDY
10. KNOWLEDGE GAPS
11. REFERENCES & LINKS
12. DISCLAIMER


## 1. Introduction

Compartmentalisation is defined as splitting up an area into smaller units or compartments (Asselman et al., 2008, p. b). In most cases, dike rings are compartmentalised or split up into smaller dike rings, while the land is usually left intact. This Delta Fact looks at the compartmentalisation of the storage basin system, in other words "in the water". The Delta Fact: Reduce flood risks by compartmentalisation dikes concerns compartmentalisation on land.

Compartmentalisation can help protect the storage basin system by:

- mitigating flood risks; mitigating the consequences of dike breach by reducing the size of floodplain areas or as a means of prevention by reducing/minimising the load on dikes.
- preserving the water quality by containing contamination and/or protecting vulnerable areas.

There are different types of structures that can be used to achieve compartmentalisation in the storage basin, including inflatable weirs, shutter weirs and floodgates. The concept of compartmentalisation of storage basins is not new. So-called BWO barriers (Wet Bescherming van de Waterstaatswerken in Oorlogstijd; Protection of Waterworks Structures in Wartime Act) can still be found in the storage basin systems of the low-lying areas of the Netherlands (e.g. in the management areas Rhineland and Delfland). These barriers were built around 1952 and were designed and installed to protect waterworks structures in wartime. The BWO Act expired in 1991.

## 2. Related topics and Delta Facts

Keywords: BWO, storage basin system, emergency flood defence

Delta Facts: Reduce flood risks by compartmentalisation dikes, impact rapid decrease in water level

## 3. Multilayer strategy

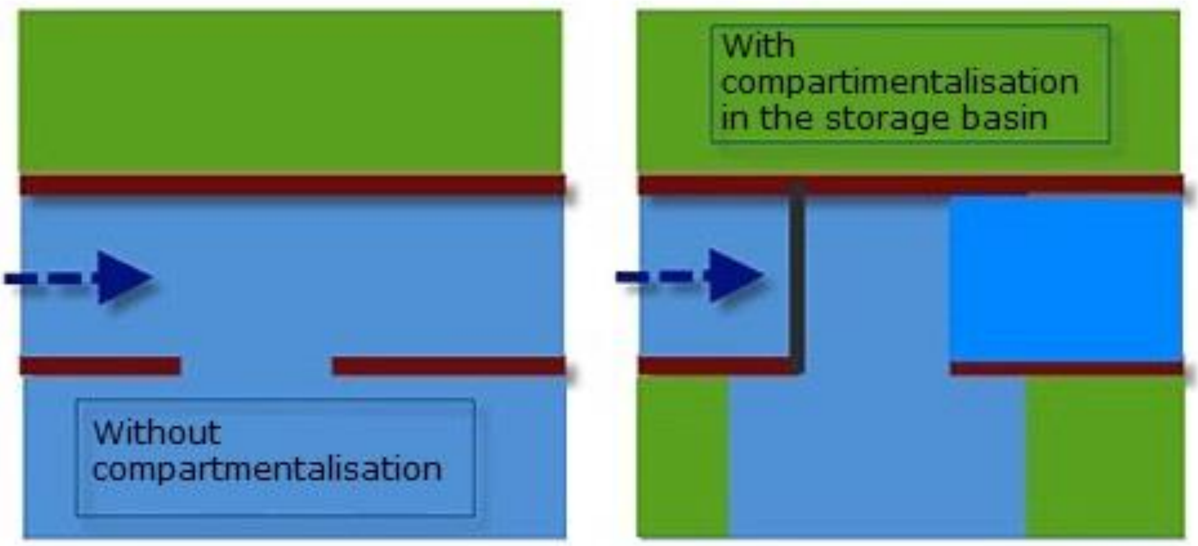
**(1 Prevention, 2 Spatial Planning, 3 Crisis Management)**

A distinction can be made between the use of compartmentalisation as a structural measure (prevention) or as an emergency measure (crisis management). When used as a structural measure, the flood defence is integrated in the system. At this level, compartmentalisation can serve as a prevention and risk reduction (helps in meeting the standard) measure. Compartmentalisation of storage basin systems helps reduce the probability of extreme levels and therefore breaching. It can also reduce the load on dikes, minimising the risk of dike breach.

Compartmentalisation as an emergency measure, for managing disasters such as embankment failure, by definition requires flexibility and immediate action to mitigate the ensuing damage as much as possible. The first course of action is to look at mobile solutions, as these can be implemented quickly in the right place. Compartmentalisation structures serve to mitigate the consequences of a breach by reducing the amount of water that may run off into the polder behind the dike as a consequence of the breach (STOWA, 2011). An example is Wilnis. To prevent further hydrological damage (after the breach), the ring canal was compartmentalised with sheet pile walls and clay dams. This allowed the rest of the area to be restored to its original condition shortly after the shear was discovered.

## 4. Schematic

Compartmentalisation is implemented in storage basins to mitigate the consequences of an imminent breach. This is shown in the figure below. The figure on the left shows a breach in the secondary dike (brown line). The water runs off from the storage basin into the adjacent polder, causing the water level in a large section of the storage basin to decrease and create extensive damage in the polder. The storage basin depicted in the figure on the right is compartmentalised. As a result, the water level in a large section of the storage basin will remain constant with minimum runoff into and therefore less damage in the polder.

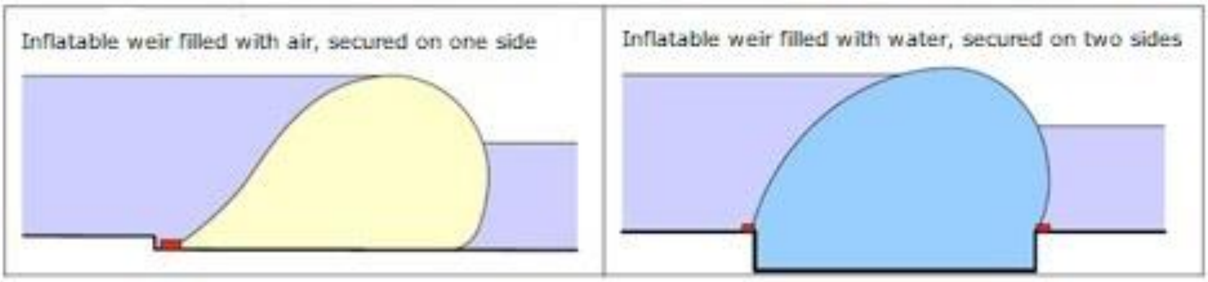



There are different types of permanent compartmentalisation structures. The Rhineland water board, for example, operates the following types: inflatable weirs, shutter weirs, stop logs, sliding structure, lift gates, floodgates and lockable culverts (Nelen & Schuurmans Consultants, 2004).

Mobile (temporary) compartmentalisation structures are used in emergencies (imminent breach) to allow for maximum flexibility and immediate intervention in the affected area. Clay, rubble, sheet piling, big bags, ramps or sandbags can be used for temporary closure of the storage basin.

## 5. Technical operation

The purpose of compartmentalising storage basin systems is to reduce the amount of water runoff into the polder after a breach in the secondary dike. As indicated above, different types of barriers can be used for this purpose. The barriers come in different versions. The figure below shows two versions of an inflatable weir. The weir on the left is filled with air, while the version on the right is filled with water. The cross section may also vary (Jongeling, 2006).




It should be noted that each type of barrier has its pros and cons. The following factors need to be considered when selecting a barrier:

- depth and flow velocity of the storage basin (in relation to the load (pressure) which may occur when the compartmentalisation structure is taken into service) and the water level to be retained (Van Ketwich in Keizer; 2008)
- access to the structure to put it into service and to manage and maintain it or to put temporary solutions (big bags) in place (Van Ketwich in Keizer; 2008). Compartmentalisation is not frequently used, but it does require maintenance. For compartmentalisation to be used, the compartmentalisation structure must be easily accessible.
- width (span and stress concentrations) and stability of the embankment where the compartmentalisation structure must be integrated (Van Ketwich in Keizer; 2008).
- material (material choice has an impact on costs as well as on the necessary maintenance. This varies with the type of material used: above or underwater materials).
- operational closing time

| Barrier type | Operational closing time | Observations |
|---|---|---|
| Inflatable weir | 60 min. | At 3m depth |
| Shutter weir | 15 min. | If hydraulically driven (depth independent) |
| Stop logs | > 60 minutes | Time-consuming mobilisation of crews to site; operation is manual |
| Sliding structure (horizontal)/Floodgate/Lift gate | 10 min. | |
| Lockable culverts | 5 min. | Very fast closure, because only one small drainage opening needs to be closed |

*Source: Interview with T. Jongeling, (Deltares, 2012)*

Note: Effectiveness of closing time also depends on the warning phase and mobilisation time that precedes it.

## 6. Positioning

Compartmentalisation is one of the measures that can be used within the multilayer safety strategy. There are various arguments that can be made in favour or against compartmentalisation. A risk involved in using a compartmentalisation structure is that in some cases it cannot be closed due to the high flow velocities near the breach (Spijker et al., 2005).

| Pros | Cons |
|---|---|
| flood compartment prevents the entire storage basin from draining, especially into large and deep polders, and causing damage to long stretches of the embankment, houseboats and other infrastructure. Closing of a compartment will reduce the outflow area to the polder by 30 to 90 percent compared to "taking no action" (Sonneveldt & Broersma, 2005; 16). | closure of compartment will cause the water level in the compartment to decrease more rapidly (and sustain damage as a result of drying out), whereby the secondary dikes may sustain damage, which may be even greater than the inundation damage in the polder itself (Sonneveldt & Broersma, 2005; 16/ Spijker et al., 2005). See also Delta Fact impact of rapid decrease in water level on flood defence |
| reduces damage to natural resources and habitats; e.g. the free flow of fish through the breach or damage to natural banks (Spijker et al., 2005) | drainage of (surplus) water is obstructed in a section of the storage basin system. Installation of the compartmentalisation structure in a storage basin system may cause significant interference with the primary function of the storage basin system (supply and discharge of water), whereby the measure - if installed prematurely - will be counterproductive. |
| prevents disruption of the shipping traffic in a large area after an embankment breach (Spijker et al., 2005) | Compartments can cover a large surface area, where additional emergency measures may be needed to reduce to reduce the flood damage in the polder (Nelen & Schuurmans Consultants, 2004). |
| compartmentalisation can be used in a multifunctional manner. Except in the event of an embankment breach, it can be used in environmental disasters or for changing the direction of current flow during extreme drought events (Spijker et al., 2005) | |

## 7. Governance

Prior to installation, a choice needs to be made between installing the compartmentalisation structure above (integrated with the embankment) or under water. This choice has an impact on the interests of stakeholders in the area where installation is to take place:

- An advantage of underwater installation is that it will not disrupt commercial shipping and recreational boating activities nor will it mar the landscape. However, to allow management and maintenance of a compartmentalisation structure to take place, a water manager must desiccate part of the storage basin.
- An advantage of above-water installation is that the compartmentalisation structure can be seen, which gives a greater sense of security. It is also easier to maintain. But less aesthetically pleasing as it blemishes the landscape. Depending on the type, compartmentalisation structures (e.g. lockable culverts) can also obstruct the passage of vessels.

A compartmentalisation structure is not frequently used, but it should work as an emergency measure. This means that besides management and maintenance, a compartmentalisation structure also requires exercises and monitoring to ensure that the structure does not fail after installation, for example as a result of excessive deposition in front of the structure, preventing it from closing.

## 8. Costs and benefits

The benefits of mitigating the impact of embankment failure are the reduced damage that may occur as a result of embankment failure (Nelen & Schuurmans Consultants, 2004). The reduced damage consists of (1) less damage in the polder and (2) less damage to embankments by the decrease in water level across a small section (Sonneveldt & Broersma, 2005).

The costs for existing emergency flood defences typically involve management and maintenance. In the event of construction of a new or temporary compartmentalisation structure, these costs consist of investment costs for construction, maintenance and training.

If the benefits from the reduced damage outweigh the costs of the barrier, construction is a valid option. Where secondary dikes appear to be more compromised (in certain places) than previously assumed, the failure probability will be higher, which translates into more frequent benefits (increased frequency of overflow events in the polder behind the dike) and more cost-effective emergency flood defences. (Sonneveldt & Broersma, 2005; 17).

## 9. Lessons learned and on-going study

Lessons learned by different water boards:

The **Rhineland Water Board** has had a number of studies conducted into the benefits of emergency flood defences, given the 86 emergency flood defences in their storage basin system. They were tested in different situations to determine when they can be used as a retaining structure and whether the barriers should be retained. According to the findings, most of the structures are useful and should be retained, however, given the costs and limited flexibility, the number of permanent emergency flood defences will not be expanded. The Rhineland Water Board has much interest in flexible solutions.

The **Hollands Noorderkwartier Water Board** has looked at various scenarios for isolating the management area in the event of a problem; 1) Required structural measures to reduce the normative load on barriers by installing compartmentalisation structures in conjunction with drainage. In establishing the standards for the regional barriers, the province has agreed to a combination of reinforcing flood defences and compartmentalisation structures. The province has expressed its willingness to adjust the standards for regional flood defences if there is proof to substantiate that compartmentalisation can contribute to achieving the established safety standards in a cost-effective manner (Hoevers and Evers, 2008, p. 9/10). 2) Set up a disaster management organisation using flexible compartmentalisation structures.
The Hollands Noorderkwartier Water Board (HHNK) has decided to build a new compartmentalisation structure (sliding structure or shutter weir) and to improve three existing structures (inflatable weir and lock gates). Where the disaster management organisation is concerned, the question to be considered is: "would you invest in prevention or mitigating consequences?". Several alternatives are provided: 1) implement structural measures for secondary dikes that do not meet the standard; 2) reduce the protection level of different secondary dikes and complement with compartmentalisation structures; 3) centralise disaster management organisation and focus its efforts on temporary (flexible) compartmentalisation structures. The HHNK is currently conducting tests by

simulating an embankment breach to determine which solutions are suitable for the disaster management organisation.

**Waternet** has been commissioned by the Amstel, Gooi and Vecht (AGV) Water Board to improve the dikes along the Gein and to conduct a compartmentalisation study in this context. The dikes in this area sit amidst trees, to which high landscape values are ascribed. However, trees on dikes are not desirable as they can compromise dike safety. The study has contributed to a better understanding of how compartmentalisation of the storage basin area near the Gein effectively reduces consequential damage in the polder behind the basin in the event of a disaster. Flood simulations were used to determine the impact of a possible breach in the event of a disaster. The study shows that consequential damage can be significantly reduced by using compartmentalisation as an emergency measure (Bolt, 2010). Closing the Gein in the event of a disaster only has a limited effect on the rest of the storage basin.
In 2012, the AGV adopted a Dike Improvement Plan in Draft for the dikes along the Gein. It contains a risk mitigation measure in the form of compartmentalisation. When a tree falls over and creates a hole in the dike the probability of a dike breach and/or inundation increases. The Gein will then be closed with a temporary weir or stop log in a separate compartment. The hole in the dike can then be closed under controlled conditions and the compartmentalisation structure removed (Heijn and Stolker, 2012).

**De Stichtse Rijnlanden Water Board** has a total of 40 compartmentalisation structures (sliding structures, stop logs, metal tubes and weirs) in the management area. These are very rarely used, however. A practical example: Running along the boundary of the De Stichtse Rijnlanden management area is the Meye, which is connected to the Nieuwkoopse lakes through a number of watercourses. Multiple compartmentalisation structures are needed to prepare for possible breaching of the Meyekade, whereby the breach location also plays a significant role. Therefore, mobile compartmentalisation will be used in the event of a breach. The disaster management plan identifies regional and other flood defences where the damming-up devices (weirs, etc.) of the Meye and connecting watercourses are located and each bridge where big bags are to be placed depending on the breach locations.
In 2009, a study was conducted to determine whether it would be possible to close the artificial watercourses through compartmentalisation and to manage fewer regional flood defences (Compartmentalisation of artificial watercourses in Old

Rhine). Two situations, breach and imminent breach, were considered to determine whether the artificial watercourse should be closed by a floating weir system or stop log (compartmentalisation structure). In addition, the location of the compartmentalisation structures was also examined to determine whether they are located in the right place in the storage basin system and are effective in reducing damage. In a SOBEK flood model a number of breaches were simulated along the water bodies to determine how much water flows through the breach in 72 hours and how much damage can be mitigated with compartmentalisation. It was found that existing compartmentalisation structures in rural areas reduce damage by 90-97%, unlike in urban areas where 48% damage reduction is achieved, given that the ("manual") response time accounts for a significant amount of residual damage remaining. It was found that no additional profit can be made from installing additional compartmentalisation structures, it does not matter if you have closed after 4 or 6 hours. Profit could be achieved if closure were to be made within one hour after the breach. This requires optimisation of the system, where with a press of a button a compartmentalisation structure can be closed. This is very cost-intensive however. No further proposal has been made for this. A number of areas have also been identified where little or no compartmentalisation can be achieved; this would require a plan for flexible compartmentalisation with big bags for instance.

The **Delfland Water Board** manages 26 BWO barriers with a compartmentalisation function: lift gates or stop logs. All these barriers were refurbished and OSHA-proofed a few years ago. The barriers can be used during emergency situations and are described in the Disaster Response Manual maintained by the disaster management organisation. The results of a large number of Lizard Flooding sums can also be used to determine their effectiveness during disaster management.

**On-going study** on temporary compartmentalisation structures:
The BoxBarrier is a modular flood defence system consisting of synthetic boxes, which are connected with sealed joints (see photo). Each box is covered by a lid before filling with water. The BoxBarrier can currently be used for compartmentalisation in 0.5m water or less. The intention is to use the BoxBarrier in deeper water in the future. Delft-Blue Technology is currently in the process of developing a demo and test site.

## 10. Knowledge gaps

There are few knowledge gaps in the area of compartmentalisation barriers. Compartmentalisation has already been tested; there is no need for performing calculations and testing mechanisms. Insight into the different challenges in installing a permanent structure has been gained through experience. There are more challenges and uncertainties with regard to temporary (flexible) emergency flood defences with clay, rubble, big bags or other systems, such as the BoxBarrier, because these cannot be calculated in advance. The identified knowledge gaps/uncertainties from the interviews are as follows:

- Real time factor; what is a realistic assumption for closing the storage basin with a temporary compartmentalisation structure? How much time will it involve? What is lacking is a sense of what a real time factor is (in which order/category). This largely determines the consequential damage in the polder.
- Protocols and closure certainties; uncertainties about closure certainties and protocols; structures can be rejected due to the lack of adequate closure certainty or protocols (closure/process of closure/decision-making; lack of roadmap). A barrier may be sufficiently strong, but the protocols are not standardised. Moreover, there is little understanding among the different water boards about the cohesion of closure protocols at border areas. How can these be coordinated and what kind of action should be taken? - Usability of big bags; are big bags a solution for temporary compartmentalisation in a peat area, given the lower stability of peat dike? How many do you need for this to be successful?
- Breakpoint of sluice locks during closure; at which flow velocity can the manual wooden logs or circular metal tubes be used for

compartmentalisation? At which flow velocity will floodgates break during closure and increase the potential for damage?

## 11. References & links


- Amstel, Gooi and Vecht results in significant damage reduction, H2O (3), p. 33-36
- Bolt, R.H.R (2010), Compartimenteringsstudie; Het Gein, Waternet 10.009157
- Heijn, K.M. and Stolker, C. (2012), Dike Improvement Plan in Draft: The Gein dike improvement, a safe and aesthetically pleasing dike, Waternet, commissioned by the Amstel, Gooi and Vecht Water Board, 12.027239.
- Hoevers, R and Evers, J.W. (2008) Voortgangsrapportage regionale waterkeringen, Hollands Noorderkwartier Water Board 08.30701.
- Jongeling, T. (2006), Dynamisch gedrag van balgconstructies, Land + Water, no. 5.
- Jongeling, T.H.G, Vrijburcht, A. (2005); 'Hydraulische aspecten van balgstuwen en balgkeringen'; edition: Bouwdienst-RWS and WL | Delft Hydraulics
- Keizer, A. (2008), Leidraad voor beperking overstromingsschade na doorbraak regionale waterkeringen, graduate research at the TU Twente.
- Nelen & Schuurmans Consultants (2004), Study on emergency flood defences in Rhineland, commissioned by the Rhineland Water Board, file F0006
- Nelen & Schuurmans Consultants (2011) Optimisation of secondary dikes and storage basin system; more stringent standard, assessment and measures, commissioned by the Hollands Noorderkwartier Water Board, project L0139
- Sonneveldt, S. and Broersma, L. (2005) Noodwaterkeringen zijn nuttig, maar niet voldoende, H2O (3), p. 15-17.
- Spijker M., Keulen M. van, Vendrik L., Graaf J. de (2005), Compartmentalisation of storage basin
- STOWA (2011), Leidraad waterkerende kunstwerken in regionale waterkeringen, ISBN 978.90.5773.529.5
- Zantvoort, M (2012), Effective compartmentalisation in de Stichtse Rijnlanden II, Hydrologic, commissioned by the HDSR, P254

Guidelines: IPO guideline for Secondary dikes 1999
Review guideline for safety of regional flood defences, 2006


*This Delta Fact was prepared by Deltares, August 2012.*

stowa

**Authors**

- L. van Vliet
- N. Asselman
- The Delta Fact is based in part on external interviews with and reviews of:
- Mr J.T.I.G. Tigchelaar (Delfland Water Board), Mr P. van den Berg (Rhineland Water Board)
- Mr N. Minnen (Rhineland Water Board)
- Mr E. de Groot (Rhineland Water Board)
- Mr M. Poort (Hollands Noorderkwartier Water Board)
- Mr R. Weijs (de Stichtse Rijnlanden Water Board)
- Mr R.H.R. Bolt (Waternet)
- Mr K.M. Heijn (Waternet)

## 12. Disclaimer