# A MULTI-LAYER FLOOD SAFETY APPROACH TOWARDS RESILIENT CITIES

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## ABSTRACT

*The multi-layer safety approach focuses on flood risk reduction through three types of measures: (1) prevention through dikes, levees and dams , (2) a flood resilient spatial planning and (3) an adequate crisis management. Whereas the official Dutch policy propagates the multi-level safety approach, the current Dutch water safety policy is still focused on prevention only (layer 1). The integration with the two other layers (i.e. a flood resilient spatial planning and an adequate disaster management) has still to be explored. In order to assess the technical and the organizational feasibility of the multi-layer safety approach in urban areas, the Province of North-Holland and the Waterboard Hollands Noorderkwartier have initiated a case study. In this case study various stakeholders of a pilot area were invited to discuss about the opportunities of the multi-level safety approach. The case study and accompanying workshop showed that an integration of the different policy layers (i.e. dike reinforcement, spatial planning and disaster management) adds much complexity to the decision environment of the stakeholders, both in technical and organizational terms. A first requirement of the stakeholders involved in such decisions was understandable information about flood risks and an integration of flood risk information with the different policy fields of spatial planning and flood disaster management. The applied 3D visualization and high detailed 2D inundation model was highly appreciated to provide this information.*

## KEYWORDS

2D inundation modelling, 3D stereo visualization, flood resilient spatial planning, flood disaster management, multi-level safety, urban flood risks

## 1. INTRODUCTION

The multi-layer safety approach (EU 2005) embodies a method for flood risk reduction through a combination of levees and dikes (layer 1), spatial planning (layer 2) and crisis management (layer 3). Until now, the focus in Dutch flood risk policies has been mainly on strong levees and dikes (layer 1). In the future, a coherent approach is required with waterproof spatial planning (layer 2) and adequate crisis management (layer 3) (Stive, Fresco et al. 2011).

The current water safety policy in The Netherlands prescribes a 5-yearly maintenance cycle for levees and dikes, consisting of sampling and testing, standardizing and reinforcement (STOWA 2008). Flood risk reducing measurements through spatial planning are barely considered in this maintenance cycle. For example, possibilities of flood risk reduction through spatial planning are local protection of hospitals, schools and utility companies. Apart from the focus on layer 1, disaster management (layer 3) has retrieved increasingly more attention. Evacuation plans and scripts have been put together and tested in flood disaster exercises (Leskens 2013). However, flood risk adaptive spatial planning to improve the possibilities for evacuation are not yet topic of investigation. For example, elevation of regional roads can prolong the time window of an evacuation (McCarthy, Tunstall et al. 2007; Kolen 2012). The lack of measures in the field of spatial planning and disaster management portraits the current one-track approach, focused on reinforcing levees and dikes, instead of an integral risk reducing policy.

Because of the one-track approach in layer 1, much of the potential of the multi-layer approach is still unknown. The policy on water safety keeps focusing on the strengthening of levees (layer 1); the layer where most funding is allocated to (Kabat, Fresco et al. 2009). Examples from countries like the UK or Japan however, show that much more can be done when it comes to spatial planning and disaster management (Okumura, Suzuki et al. 1998; Hall, Meadowcroft et al. 2003).

## 2. METHOD

### *Case study set up*

In order to assess the technical and the organizational feasibility of the multi-layer safety approach in urban areas, the Province of North-Holland and the Waterboard Hollands Noorderkwartier have initiated a case study. Also the Delft University of Technology, Deltares and Nelen & Schuurmans Consultants were involved, as members of the 3Di Water Management consortium. This consortium developed a high detailed 2D inundation model, accompanied with a 3D visualization, which was applied in the case study. Various stakeholders of the pilot area West-Friesland were invited to discuss about the opportunities of the multi-level safety approach. The West-Friesland area is a large flood prone area (781 km$^2$) in the province of North Holland, laying approximately 3 meters under sea level. It is protected by dikes from water in the Ijsselmeer/Markermeer-lake. The area is inhabited by approximately 400 000 people. A broad work session was organized to create a decision-making environment in which various stakeholders in the area were informed about the flood risks and were involved in investigating mitigation measures in spatial planning and flood disaster management. 35 stakeholder attended the workshop. This group existed of representatives of the province of North-Holland (official organizer of the workshop), the Waterboard, municipalities, agriculture, business, project developers, energy providers, health service, fire department and an insurance company. These stakeholders covered most of the parties involved in choosing mitigation measures.

The workshop had a duration of 4 hours with the following agenda:

1. Technical background of flood risk issue
2. Generating prevention and mitigation measures in small groups, divided to different types of stakeholders (i.e. water managers, spatial planners, disaster management)
3. Presentation of generated measures
4. Group evaluation about the complexity encountered in the decision-making process in this workshop

## *Application of a high detailed 2D inundation model and 3D visualization*

To be able to answer questions such as ‘Who takes care of which measure?’ and ‘How should it be arranged?’, participants in the case study required information about the situation in case of a flooding event during the workshop. In the research program 3Di Water Management, a new interactive 2D inundation model was developed to provide this information interactively.

The water movement in the model is based on the continuity equation, which describes the conservation of mass and momentum. For shallow water this is mathematically described in the Saint Venant equations (Gerbeau and Perthame 2000):

$$\frac{\partial \eta}{\partial t}+\frac{\partial(\eta u)}{\partial x}+\frac{\partial(\eta v)}{\partial y}=0$$

$$\frac{\partial(\eta u)}{\partial t}+\frac{\partial}{\partial x}\left(\eta u^2+\tfrac{1}{2}g\eta^2\right)+\frac{\partial(\eta u v)}{\partial y}=0$$

$$\frac{\partial(\eta v)}{\partial t}+\frac{\partial(\eta u v)}{\partial x}+\frac{\partial}{\partial y}\left(\eta v^2+\tfrac{1}{2}g\eta^2\right)=0$$

Here $\eta$ is the total fluid column height. The 2D vector ($u$,$v$) is the fluid's horizontal velocity, averaged across the vertical column. $g$ is acceleration due to gravity. The first equation is derived from mass conservation, the second two from momentum conservation in two dimensions.

The numerical methods in which these equations are solved are based on recent literature, which includes four characteristic components. These components are briefly explained here. More details can be found in Stelling (2012) and Casulli and Stelling (2013)

1. The sub-grid method. In this method a distinction is made between a detailed grid and a course grid. In the detailed grid (i.e. the sub-grid) are all details about elevation and roughness taken into account at a resolution of 0,5 by 0,5 meter. This includes elevation, roughness and parameters for groundwater flow, such as interception, infiltration and seepage. In the course grid the pixels are clustered for the computation of water levels and velocities (see Figure 1).
2. Quadtrees, which allow to detail the course grid, in which the water levels and velocities are calculated, on places were the elevation grid has an high variation, for example along high line elements such as railways (see Figure 2).
3. Bottom friction based on the concept of roughness depth, in which the spatial variation of the roughness in the sub-grid is taken into account
4. The finite-volume staggered grid method for shallow water equations with rapidly varying flows, including semi-implicit time integration. This method ensures that the continuity equations are always solved strictly

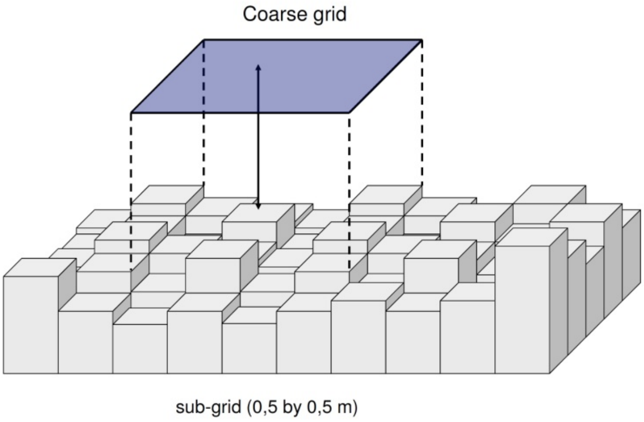

Figure 1: Subgrid method

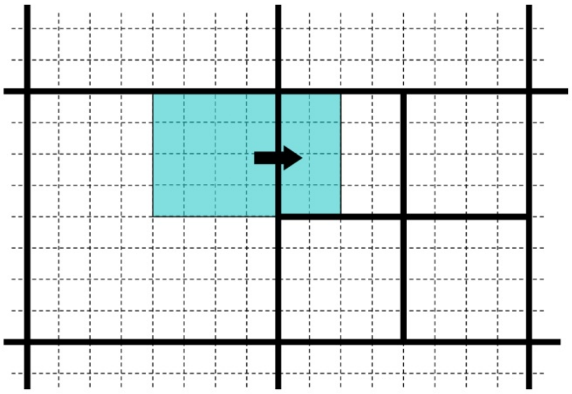

Figure 2: Quadtrees method

All spatial characteristics of the case study area were defined on the level of the sub-grids of 0,5 by 0,5 (i.e. elevation, surface roughness, interception, infiltration rate, crop type and the porosity and permeability of the soil). These parameters were derived from the following sources: Objects database of the water board, Actual Heights of the Netherlands, version 2 (www.ahn2.nl), New Land Use Map of the Netherlands (www.stowa.nl), Soil map of the Netherlands (www.stiboka.nl) a conversion table to convert land uses to roughness values, infiltration rates and interception and a conversion table to convert soil types to permeability values and porosity values (CultuurtechnischeVereniging 1988).

Two dam breaks were calculated with the model, each on a different location. An extreme high water scenario was modelled, based on a return time of 10.000 years. The scenario details are listed in the table below. The dam break locations are shown in figure 3

*Table 1: Scenario details*

| | |
|---|---|
| Return time high water event | 10.000 year |
| Maximum water level (over 8 hours) | 1,25 m NAP |
| Start and end water level | -0,40 m NAP |
| Duration high water event | 64 hours |
| Surface level at dike breach | 0,33 m NAP |
| Dike breach width | 50 m |
| Dike breach depth | 0,33 m NAP |
| Scenario time | 30 days |

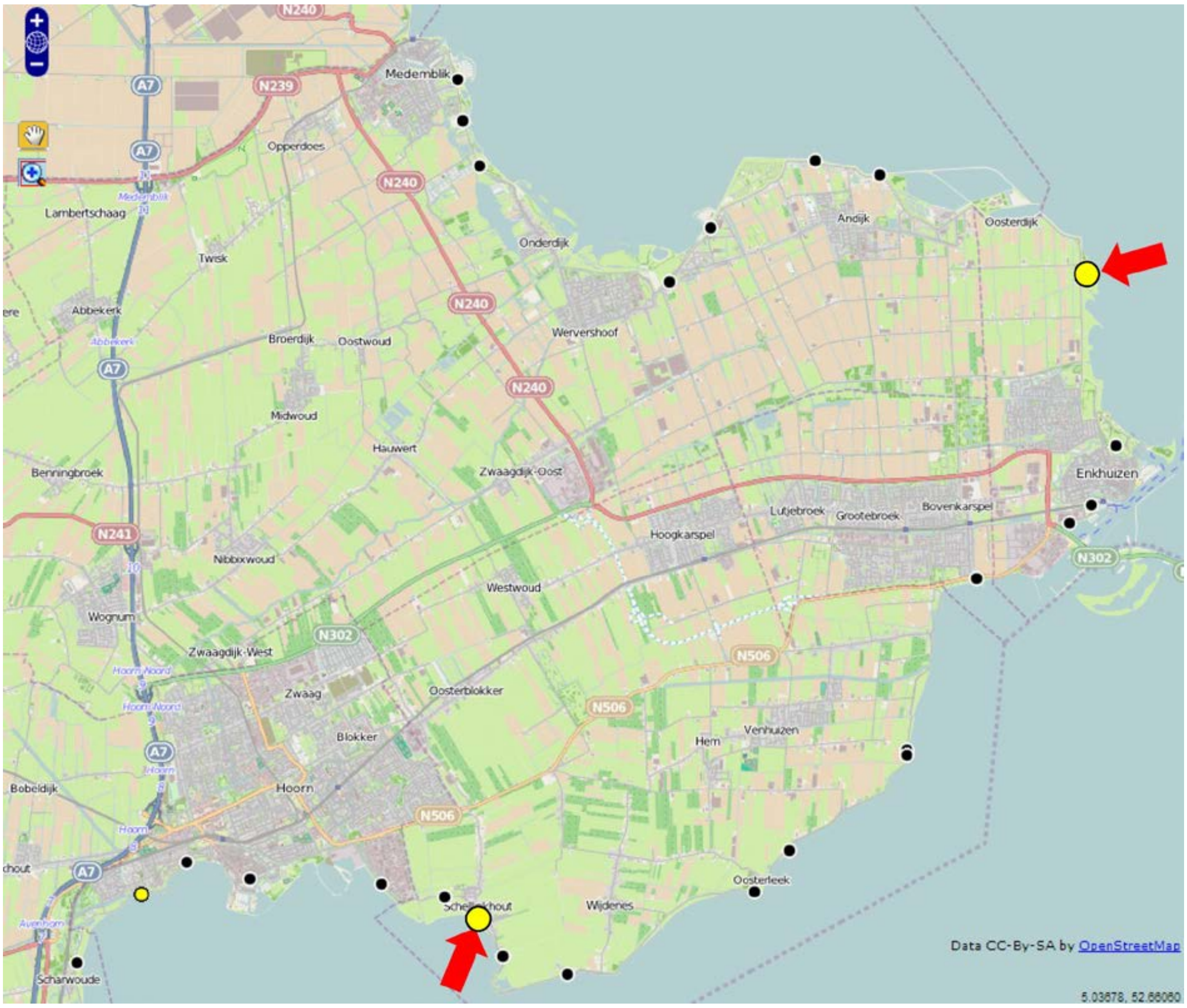

*Figure 3: The case study area and the two dam breach locations*

The detailed flooding results were used as input for damage calculations. By using a damage calculator, developed by the national waterboard research institute STOWA, damage calculations with a resolution of 1 by 1 meter were made. The calculated damage is based on the following formula:

$$Damage = Direct\ damage_{max} \cdot \gamma_{depth} \cdot \gamma_{duration} \cdot \gamma_{seaon} + Indirect\ damage \cdot restore\ time$$

Here, the *Direct damage*$_{max}$ is the replacement value, $\gamma_{depth}$ a factor related to the inundation depth, $\gamma_{duration}$ a factor related to the inundation time, $\gamma_{season}$ a factor related to the agricultural grow seasons, *Indirect damage* the damages per day caused by loss of income and the *restoration time* the number of days with a loss of income. More information about which factors are used and how the maximum direct damage and indirect damage are derived per land use class is provided in Hoes et al (2013).

## 3. RESULTS

### *Outcomes of the 2D inundation model*

The high water scenario was calculated at both dam breach locations separately. The model output consisted of an inundated area over time, visualized in flood animations (see Figure 4). Details are provided in Table 2.

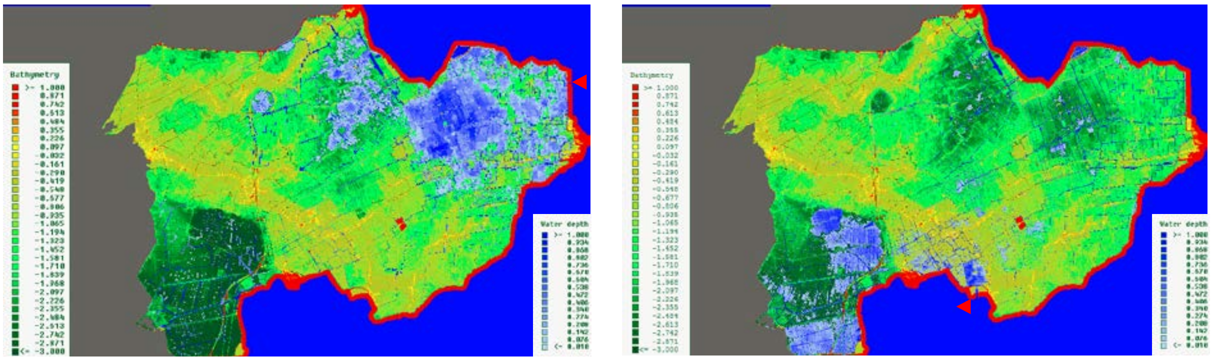

Figure 4: Inundation after 12 hours for both dam breaches

Table 2: Results dam breach calculations

| | Dam breach northeast | Dam breach south |
|---|---|---|
| Inundated area (total 781 ha) | 635 | 469 |
| Inundated area [%] | 81% | 60% |
| Calculated damage [milion euro] | 2174 | 1366 |

The model results have been post-processes in maps, useful to consider measures in flood disaster management and spatial planning. The calculated damage has been categorized in 3 different categories: 1. Flooded roads: highways, secondary and urban roads; 2. Flooded utility companies: divided in electricity, gas and water; 3. Flooded vulnerable objects; hospitals, day care centers, schools and elderly homes. Also maps that indicate the arrival times of the flood were generated, in order to provide information to plan evacuations. Figure 5 shows two examples of the post-processes maps for a city in the area. The left figure indicates the arrival times of the flood and the right figure indicates the accessibility of roads.

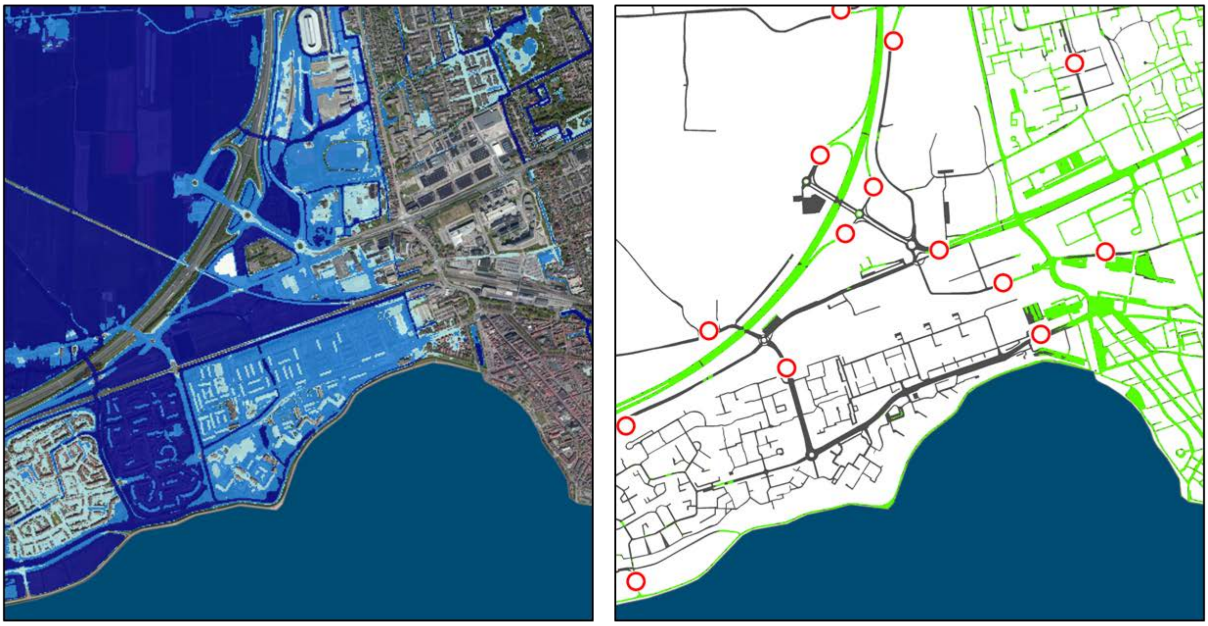

*Figure 5: Detailed maps with arrival times in a flooding event and road accessibility used in the West-Friesland workshop.*

Visualization in stereo 3D resulted in a grasping view on the effects of a flooding event (*Figure 6*).

*Figure 6: 3D stereo visualization of a flooding event with 3Di instruments*

***Results of the workshop***

During the workshop, the stakeholders were divided into groups to answer the central questions: ‘Which measures can be taken?’ and ‘How can these measures be implemented?’. Because of high computations speed of the 2D inundation model, ideas of the stakeholders that came up during the workshop could immediately be tested in the model. One of the measures that came up during the workshop, dividing the area in different components by ‘dry dikes’, is shown in figure 7.

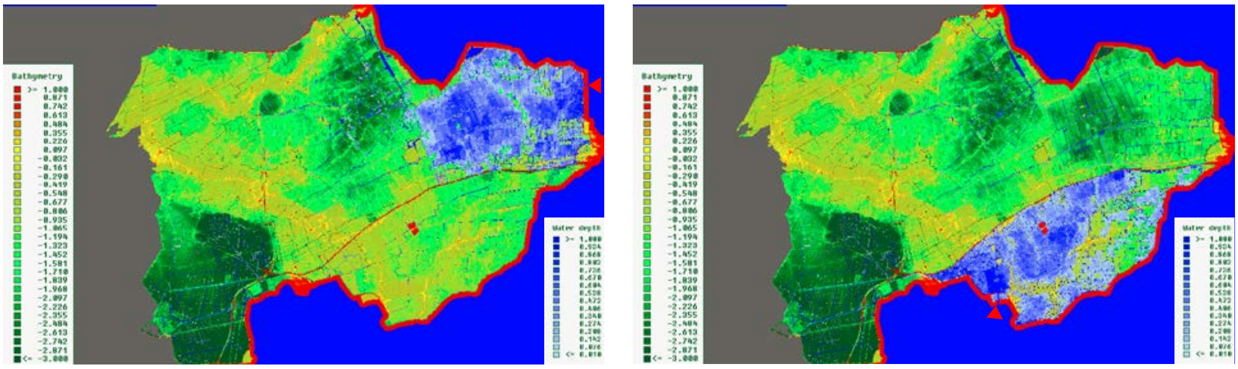

**Figure 7: Effect of dividing the area in a southern part and a northern part by a dry dike (red line) at both dam breach locations**

Various opportunities to decrease flood risks by measures in spatial planning or enhancements in flood disaster management were brought up by the stakeholders in the workshop, listed in the table below.

*Table 3: Who can contribute in which way in layer 2 and 3?*

| **Stakeholder** | **What** | **How** |
|---|---|---|
| Province | Include water safety in water regional planning | Use official strategic plan for spatial planning and raise and maintain regional roads in order to provide evacuation routes |
| Municipality | Incorporate water safety in building standards and regulations | Adapt official building standards |
| Water board | Create awareness and inform stakeholders on water safety<br>Apply the water system to reduce flood risks, for example, by using compartments in discharge canals | Supply flooding data and information on a non-expert level<br>Apply the water system for flood reduction and practice |
| Suppliers of energy and water | Ensure drinking water during flooding events, by keeping the system under pressure<br>(Electricity supply and communication systems tend to break down easily) | Keep pumping stations dry and assure emergency power supply<br>Redirect mobile communication supply towards flooded area |
| Companies and entrepreneurs | Take private measures in case the level of protection ensured by the water board is not enough | Take local measures such as dikes around the property |
| Inhabitants | Take private measures to survive for a longer period in case of flooding | Prepare a survival-kit |
| Emergency services (fire departments, police) | Switch from procedural scripts to scenario-related evacuations | Enhance evacuation scripts and the supply of information during calamities |

## 4. CONCLUSIONS

From the case study West-Friesland it can be concluded that the multi-layer safety still remains a theoretic approach, rather than an imbedded policy. For many stakeholders, it seems hard to grasp that efforts are put in the prevention of flooding, but at the same time at risk reduction to minimize the impact in case of flooding.

At this point, the Dutch water safety is a one-track policy instead of multi-layered. The measures for prevention, spatial planning and crisis management are either ‘non-existing’ or barely in tune with each other. The reason can be found in the different organizations and responsibilities in the different layers. Also, the amount of regulation differs from layer to layer. For example, in layer 1 there is a strict regulation with a five yearly maintenance cycle, whereas regulation of water safety in spatial planning is almost non-existing.

Spatial planning can be the link in the integration of the different layers of water safety. After all, measures through spatial planning contribute to risk reduction in case of local protection, as well as disaster management and prolongation of the evacuation duration. Regional governments, such as municipalities and provinces, should be appointed to stimulate the debate and make policy on water safety. A crucial first step is to create awareness. During a workshop in West-Friesland, a 3D visualization of flooding effects strongly contributed to the willingness of the stakeholders to cooperate and contribute to increase water safety. A second step is to implement water safety in the policies for spatial planning, such as regional spatial planning and construction regulations. Also structural measures such as compartment of local protection are mentioned as possibilities.

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