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COPING WITH CLIMATE CHANGE IN A DENSELY POPULATED DELTA: A PARADIGM SHIFT IN FLOOD AND WATER MANAGEMENT IN THE NETHERLANDS†

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ABSTRACT

The expected effects of climate change and economic and population growth have motivated the Netherlands Government to reformulate their policies on flood protection and water management. Flood protection and drainage are needed to make this low-lying country habitable and suitable for agriculture and other land uses: more than 65% of the Netherlands is protected by dykes against flooding. The likely impacts of climate change in combination with socio-economic developments call for proactive and innovative plans. The new policies and standards are based on an innovative approach: instead of focussing only on prevention, the new standards take into account both the probability of flooding as well as the potential impacts and risks of flooding, for example the individual risk of being hit by a flood. Based on these new standards, conservation, adaptation and mitigation actions are used to create a multi-layer safety approach that focuses on the water management system as well as spatial planning. Examples are presented of changes in perspectives and how flood protection, water management and spatial planning are being combined. These examples can be a basis for further adaptation measures in both the Netherlands as wells as in other low lying countries world-wide.

† Prendre en compte le changement climatique dans un delta densément peuplé : une déclinaison des paradigmes dans la gestion des inondations et des eau dans le Pays-Bas

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KEY WORDS: coastal lowland development; flood protection; water management; drainage; sustainable development; land use

RÉSUMÉ

Les effets escomptés du changement climatique et de la croissance économique et démographique ont motivé le gouvernement néerlandais à reformuler ses politiques en matière de protection contre les inondations et de gestion de l'eau. La protection contre les inondations et le drainage sont nécessaires pour rendre ce pays de basse altitude, habitable et adapté à l'agriculture et à d'autres utilisations du sol : plus de 65 % des Pays-Bas sont protégés par des digues contre les inondations. Les effets probables du changement climatique combinés aux évolutions socio-économiques exigent des plans proactifs et novateurs. Les nouvelles politiques et normes reposent sur une approche innovante : au lieu de se concentrer uniquement sur la prévention, les nouvelles normes prennent en compte à la fois la probabilité d'inondation ainsi que les impacts potentiels et les risques d'inondation (par exemple le risque individuel d'être touché par une inondation). Sur la base de ces nouvelles normes, des mesures de conservation, d'adaptation et d'atténuation sont utilisées pour créer une approche de sécurité multicouche qui met l'accent sur le système de gestion de l'eau ainsi que sur l'aménagement du territoire. On y présente des exemples d'évolution des perspectives, de combinaison de la protection contre les inondations, de la gestion de l'eau et de l'aménagement du territoire. Ces exemples peuvent servir de base à une nouvelle adaptation tant aux Pays-Bas que dans d'autres pays de basse altitude du le monde.

MOTS CLÉS : développement des plaines côtières ; protection contre les inondations ; gestion de l'eau ; drainage ; développement durable ; utilisation des terres

INTRODUCTION

The Netherlands, a low-lying country in Western Europe (50º - 54º N and 3º - 8º E), consists of deltas and former flood plains of the rivers Rhine, Meuse and Scheldt (Colenbrander, 1989). The total territory, including inland lakes, estuaries and territorial waters, is 41,543 km^2, of which 55% is used for agriculture, 12% is nature, 19% is open water and the remaining 14% is built-up area (Centraal Bureau voor de Statistiek, 2014). The land area consists mainly of alluvial deposits and about 25% of the country lies below mean sea level. In the absence of dunes and dykes more than 65% of the country would be flooded at high sea and high river levels (Van de Ven, 2004). Most of the western part has an elevation varying between 0 and 5 m below Mean Sea Level (MSL) and has little relief except for the coastal dunes. The lowest point north of Rotterdam is some 7 m below MSL. To prevent these areas from flooding, 3,200 km of primary dykes have been built along the coast and the main rivers along with about 14,000 km of inland or secondary dykes (Van Baars, 2005). Drainage is needed to make these low-lying areas suitable for agriculture or other land uses. Reclamation of these lowlands started around 1000 AD (Van Der Molen, 1982; Wesselink *et al*., 2015). At that time, the land was still elevated above sea level and drainage by gravity was possible. Drainage of the peatlands and the subsequent oxidation and soil compaction caused the land level to drop and new drainage techniques were needed. From the sixteenth century onwards, windmills were introduced to pump out the water, thereby maintaining a good drained land base, but leading to further subsidence. In the 18th and 19th centuries, wind mills were gradually replaced by mechanical pumping. As a consequence, the drainage base has been lowered over time with the effect that, nowadays, instead of a few metres above MSL, these areas are now several metres below it (Figure 1).

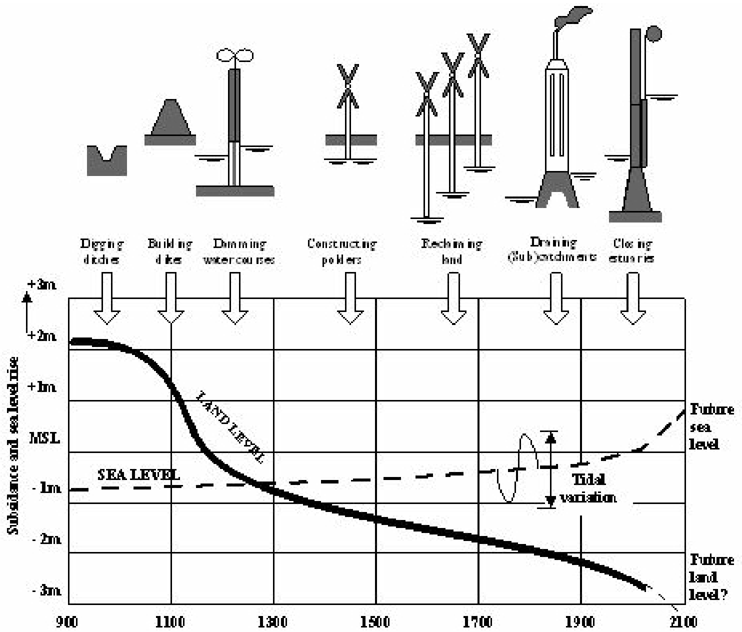

Figure 1. Subsidence, in combination with sea level rise, has always challenged the Dutch water sector (Van de Ven, 2004).

Flood risk management strategies in the Netherlands have traditionally focused on reducing the probability of flooding (Nillesen and Kok, 2015). To protect the Netherlands against flooding, the country is divided into dyke-ring areas, i.e. areas that are protected through a closed system of dykes, dunes, dams, barriers and natural high grounds (as laid down in the Water Act of 2009). This so-called polder approach refers to the drainage and flood protection of low-lying areas by means of pumps, canals and flood defences (Stijnen *et al.*, 2014). The legislation set an allowable frequency (the exceedance probability) for the water level that each dyke-ring must be able to withstand. The allowable exceedance probability does take into account the possible damage of flooding and the potential numbers of victims (Ministerie van Verkeer en Waterstaat, 2007). Compartmentalization of these dyke-ring areas is an effective method to reduce the effects of flooding (Oost and Hoekstra, 2009). The densely populated western part of the country, where the main risks come from storm surges along the coast and thus the warning time is relatively short, has the highest level of safety (1/10.000 per year) because the possible damage is very high. In the less densely populated areas in the south-west and north-east the safely level is 1/4.000 and this safely level is further reduced to 1/1.250 for the areas around the main rivers as high discharges in these rivers can be better predicted and thus there is more time for emergency measures. However predictions regarding future climate, economic and population scenarios have called these standards into question. We will discuss how the potential effects of climate change and economic and population growth have motivated the Government of the Netherlands to reformulate their strategies and policies on flood protection and water management. Although the challenges are clear, addressing them effectively will take time. What are the best methods to use? What are the best infrastructural options to control water levels, to avoid flooding and to take care of transport needs, etc.? How do you operate and maintain this infrastructure? This is a process of optimisation that in The Netherlands and other countries in Northern Europe has been going on for centuries and is still continuing. It will only be successful here and elsewhere in the world if the principles and practices of sustainable '*wise use*', especially with respect to flood protection, hydrology and water management, are taken into account. '*Wise use*' is defined as use for which reasonable people, now and in the future, will not attribute blame (Joosten and Clark, 2002). In this paper, examples, based on these '*wise use*' principles, are presented of the changes in perspective and practices regarding flood protection and water management, how risk-assessments are used, infrastructural challenges that have to be met and new adaptation strategies to overcome the never-ending risk of flooding in the Netherlands.

CLIMATE CHANGE PREDICTIONS

Over the last thousand years, the Netherlands has been subject to a sea level rise of approximately 0.7-0.8 mm $year^{-1}$ (Figure 1). Meanwhile, over the past 15 years the rate of global mean sea level rise has increased to 2 mm $year^{-1}$ (Kwadijk *et al.*, 2010). For the coming decades the predicted increase due to climate change in the mean sea level for the Netherlands are much higher: from 0.65-1.3 m by the year 2100 up to 2-4 m by the year 2200 (Delta Committee, 2008). Precipitation is also changing: in the wetter northern parts of Europe precipitation increased between 10 and 40% in the 20^{th} century, while in some parts of the drier southern regions of Europe it decreased up to 20% (Maracchi *et al.*, 2005). Over the past 50 years, the intensity of the precipitation, such as heavy rain events, has increased and these events are becoming more frequent. At the same time, dry periods in summer are projected to increase, aggravating issues such as water availability (for agriculture, nature, households and industry) and land subsidence among other things. In the Netherlands, rainfall is predicted to increase in spring, autumn and winter, but not in summer (the main growing season) (Klein Tank *et al.*, 2014). In summer, while extreme rainfall events are predicted to increase, higher temperatures will result in increased (crop)evapotranspiration and higher rainfall deficits during the growing season. A recent study over the period 1951-2009 indicates an upward trend in daily precipitation from February to April and a decreasing trend from July to September (Daniels *et al.*, 2014). This change in precipitation patterns is most pronounced along the coast (changes of 15 – 30%) decreasing to less than 5% 150 km further inland near the German border. The expected rise in temperature will also result in decreasing river flows in summer and increased flows in winter. For the river Rhine, the peak discharge, based an average annual exceedance frequency of once every 1250 years, is projected to increase from the current 16,000 m^3 s^{-1} to 18,000 m^3 s^{-1} in 2100 (De Wit and Buishand, 2007). The combined effects of the projected increase in sea level, land subsidence and increased river discharges will significantly increase the risk of flooding and complicate water management.

A PARADIGM SHIFT IN FLOOD RISK AND WATER MANAGEMENT

Flooding, from storm surges along the coast and from high discharges in the rivers Rhine, Meuse and Scheldt, has been a continuous threat to the Netherlands requiring ongoing efforts to protect the population. Over the course of history flood protection was not always given high priority: outbreaks of pest, famine or wars got often more attention (Van Baars and Van

Kempen, 2009). Poverty and a lack of knowledge also made it difficult to construct more effective and safer dykes. Dyke engineering did improve in the Napoleonic era due to the French Central Government, but not enough. Between 1134 and 2006, 337 extreme weather events resulted in approximately 1735 dyke failures. Storm surges were the primary cause of these dyke failures, followed by river floods and ice drift. Following disasters, specific legislation was often introduced, establishing administrative responsibilities and guaranteeing financial resources over a prolonged period, e.g. the Delta Act in 1958 (Rijkswaterstaat, 2006). Subsequently, the dykes and embankments were heightened and strengthened over time (Zegwaard *et al.*, 2015). After the February 1953 flood disaster in the southwest delta, which resulted in the deaths of nearly two thousand people, flooding of more than 150,000 hectares of land and an economic loss of approximately 10% of the gross domestic product, higher flood protection standards were set in the new Delta Act (Hoeksema, 2011). The corresponding Delta Plan focused mainly on improving flood protection along the coast, but in its wake the safety of the flood-prone areas along the main rivers was also increased (De Wrachien *et al.*, 2011). Balancing the costs to increase safety against the reduction in risk of flooding, the Delta Plan established varying flood protection levels for different areas of the country. As mentioned before, these standards vary from 1/1.250 per year for areas along the upper reaches of the rivers Rhine and Meuse to 1/10.000 year for the densely populated and economically vital low-lying '*Randstad*' region (Kind, 2014).

Despite these increased safety levels, extreme discharges in the river Rhine in 1995 forced the authorities to evacuate more than 200,000 inhabitants of areas along the river (Chbab, 1995). This near-disaster motivated the Government of the Netherlands to once more adapt their water safety policies. In 2006, the '*Room for the River*' programme was launched with the aim to reduce water levels during high river discharges by creating extra storage along the rivers. In 2008, the Government appointed an independent committee (the second 'Delta Committee') to prepare recommendations on how to improve protection of the coastal and low-lying parts of the Netherlands against the consequences of climate change and sea level rise. The challenge was to make the Netherlands climate proof in the future - thus safe against flooding - but at the same time keep the country an attractive place to live, reside, work, recreate and invest. The Delta Committee formulated twelve recommendations for the short (till 2050) and medium (till 2100) term (Delta Committee, 2008). The main recommendation related to flooding was to increase the present flood protection levels for all dyked areas by a factor 10. Based on these recommendations, the Government has initiated a paradigm shift in thinking about flood risk management.

Flood risk management strategies traditionally focussed on reducing the probability of flooding by strengthening dykes and embankments (Baan and Klijn, 2004). This is known as the '*technological lock-in*': a vicious cycle of investment over time to protect the continuously subsiding land against flooding (Wesselink *et al.*, 2015). The new flood protection standards are based on a different approach: instead of focussing only on prevention, the new standards take into account flood prevention as well as the risks and the potential impacts of flooding, for example the individual risk of being affected by a flood (Pötz *et al.*, 2014). The greater the risks and/or the impacts, the higher the standard. The basic protection level is the same for all Dutch people, independent of where they live: it stipulates that the risk that an individual may die as a result of flooding should be less than 1 in 100,000 per year (10^{-5}). This probability of 10^{-5} per year is lower than the risk of dying as a result of a traffic accident, but higher than the risk of dying of a so-called 'external' risk factor, e.g. the risk of dying due to contamination by chemicals or other harmful substances (which has a standard 10^{-6} per year). A social cost-benefit analysis conducted by the Central Planning Agency concluded that an increase of the basic security against flooding to this 10^{-6} per year would not be cost effective (Kind, 2014).

Next to climate change (and its related impacts) the socio-economic developments poses a big challenge to meet the new standards. Climate change will significantly increase flood risk, but less than economic development does. Even at an economic growth rate of about 2%, fatality risk will increase relatively slowly because the Dutch population as a whole will hardly increases (Klijn *et al.*, 2012). An analysis of the risks due to flooding in South Holland, one of the most densely populated provinces in the West of the Netherlands, shows that the probability of death for a person, the so-called individual risk, is small (Jonkman *et al.*, 2008). Evacuation, however, will be difficult because of the limited time available and infrastructural constraints like congested roads. Therefore the probability of a flood disaster with many fatalities, the so-called societal risk, will be higher (Maaskant *et al.*, 2009). In the past, spatial planning often ignored the dynamic aspects of adaptation resulting from the interaction between the water system and the society (Haasnoot *et al.*, 2012). The lack of understanding the dynamic interactions among the different components of risk (e.g., hazard, exposure, vulnerability, or resilience) is one of the main obstacles for the implementation of effective risk prevention measures (Di Baldassarre *et al.*, 2014). Nowadays, instead of simply increasing the safety standards, it is considered more effective to reduce the social disruption caused by flooding. Based on these considerations the new water safety policy is based on three pillars:

- basic security for everyone living in flood-prone areas;
- prevention of social disruption caused by flooding;
- protection of vital and vulnerable infrastructure.

In this approach there is a strong relationship between flood risk management and spatial planning (Nillesen and Kok, 2015) as flood protection measures will be based on a multi-layer safety approach (Figure 2) (Pötz *et al.*, 2014):

- preventive measures such as strengthening of dykes and embankments;
- sustainable spatial planning such as making compartments and constructing water-robust structures and buildings;
- disaster management and evacuation plans.

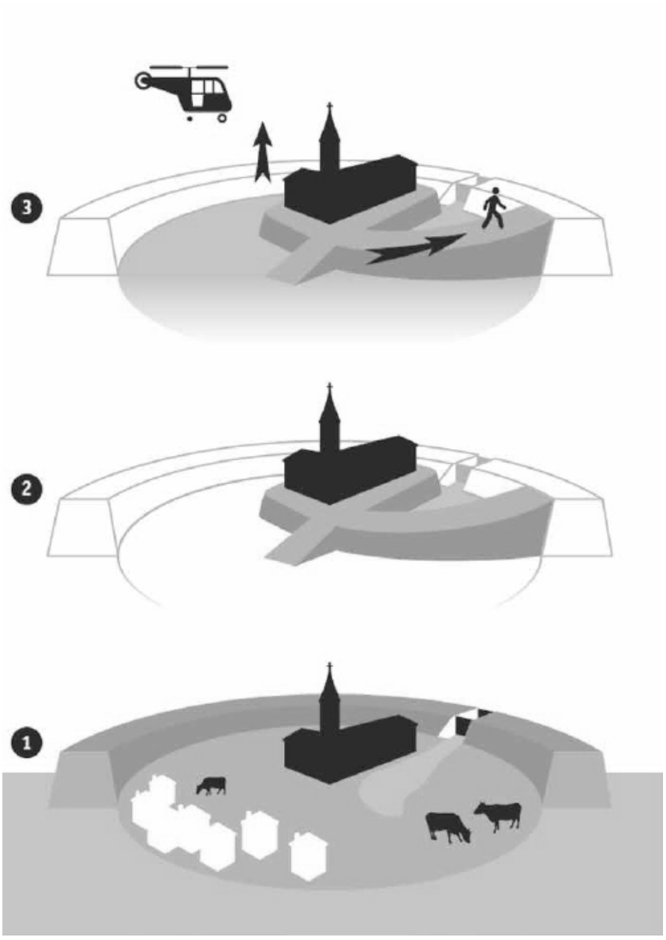

Figure 2. Flood protection measures will be based on a multi-layer safety approach; (1) preventive measures; (2) spatial planning, and (3) emergency plans (Pötz et al., 2014)

Lessons learned from a large-scale urban development project based on this multi-layer approach show that careful spatial planning can reduce vulnerability to flooding, provided that decision-makers have insight into the costs and benefits of adaptation options (de Bruin *et al.*, 2014). However, it is important to realize that these spatial planning and disaster management measures can never replace preventive measures, which in most cases will remain the most effective measure. It should be realised that there will be always a tension between flood protection, spatial developments and societal acceptance, which in combination with various other functions such as infrastructure, ecology and shipping, are all critical issues in making a flood-protection strategy successful (Stijnen *et al.*, 2014).

Next to the changes in flood-risk management, water management is also in a fundamental process of change towards a more adaptive and participatory approach (Van der Brugge *et al.*, 2005). Similar as raising dykes to reduce the risk of flooding, the solution to cope with increases in rainfall was to increase pump capacity of the drainage system. This was relatively easy as most polders in The Netherlands have a high percentage of open water (up to 25-30%) because they were initially designed for windmill pumping and therefore had to store relatively large quantities of water (Kaijser, 2002). Also for water management, the combined problems of climate change, subsidence and urbanization required a more fundamental structural change. In February 2001, the National Government, the Association of Provincial Authorities, the Association of Water Boards and the Association of Dutch Municipalities agreed on a paradigm shift in the water management approach (Delta Committee, 2008). In the new approach, instead of continuing to increase pumping and drainage capacities further and further, the focus has shifted to *controlling* drainage. The aim is to control drainage discharge and water levels throughout the year rather than simply pump out more water. This is done in a three-step approach (Figure 3): (1) retaining excess water in the field by storing the water on the soil surface and in the soil profile; (2) increasing the storage capacity in the drainage system; (3) enabling controlled removal (Ritzema and Stuyt, 2015). This approach reduces outflows during periods of extreme rainfall and increases water storage for use during periods of drought. The combined effect is beneficial for crop production and the natural vegetation, but also contributes to flood protection because peak runoff rates are reduced. Measures to implement this approach not only depend on soil and hydrological conditions but are mainly driven by the prevailing types of land use in combination with the environmental needs (Van de Sandt and Goosen, 2010).

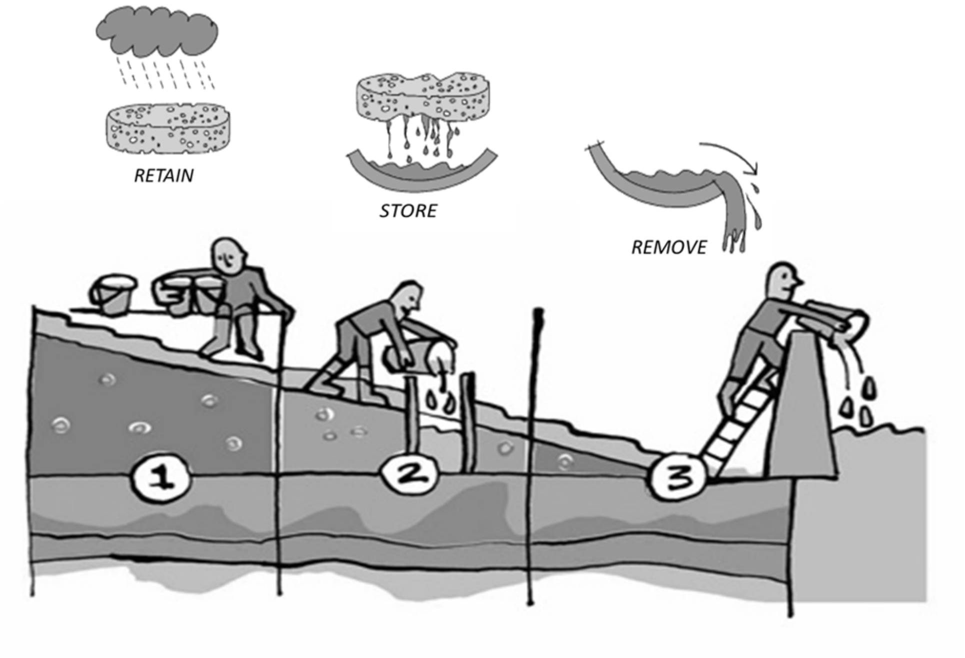

Figure 3. The focus of the water-management approach has shifted from increasing drainage intensities to 'retain, store and controlled removal' (Ritzema and Stuyt, 2015).

'*ROOM FOR THE RIVER*' PROGRAMME

In 1993 and 1995, the river Rhine experienced extreme high water levels, only in 1926 the river had a higher discharge (12,600 m^3 s^{-1}) (Klijn *et al.*, 2012). In 1995 more than 200,000 inhabitants and 1 million livestock were evacuated. After these extreme events, the idea evolved to give more space to rivers with the objective to reduce the water level during extreme river discharges. However, it took quite some time for the idea to take shape. In the 1990's, flood defences in the riverine area did not meet the existing standards because dyke-reinforcement plans had been hampered by protests of inhabitants and non-governmental organisations (NGO). They objected to traditional dyke reinforcement (which consisted of the heightening and widening of existing dykes), because of the negative impacts on the riverine nature and landscape, including the traditional houses along the dykes. Concern for ecological, economic, cultural-heritage and landscape values in the riverine area had been increasing since the 1980's, and led to the ambitious '*Plan Ooievaar*'(1986) to restore the biotic system in the Dutch riverine area in conjunction with functions like transportation, agriculture, safety and recreation (Van der Brugge *et al.*, 2005). In the Third National Dutch Water Management Plan of 1989 (Ministerie van Verkeer en Waterstaat, 1989) it was stipulated that the management of the riverine area had to be tied to ecological, economic and landscape values, safety was not a top concern at that time. Subsequently, in the early 1990's, projects to restore riverine nature were initiated, e.g. to restore the nature reserve '*De Blauwe Kamer*' in 1992 (Nienhuis *et al.*, 2002). However, immediately after the extreme river levels in 1993 and 1995 the dykes along the rivers were reinforced in the traditional way. The shock of the near flooding resulted in increased risk awareness among both policy makers and inhabitants and sped up dyke reinforcement procedures. The shock also raised awareness about the potential impacts of climate change.

The statistically expected extreme river discharges were increased after the high waters of 1993 and 1995, which prompted policy makers and Water Boards to think about new suitable responses, such as giving more space to the rivers. Instead of keeping the water between ever-higher dykes and discharging it as fast as possible to the sea, the idea of accommodating the river water offered an interesting alternative as well as an opportunity to realize the ambitions for restoration of the riverine nature and landscape. In 2006 the Spatial Planning Key Decision (SPKD) '*Room for the River*' was agreed upon. The concept of the '*Room for the River*' is based on a holistic, integrated approach embracing a multi-functional river in which flood safety is realized in combination with other values such as landscape, environmental and cultural values (Zevenbergen *et al.*, 2015). Improving spatial quality in the riverine area by restoring the typical riverine nature and landscape were important ambitions in the plan alongside the main goal of lowering flood risk by lowering the water level during extreme events. The SPKD '*Room for the River*' formed the formal base for taking measures to give more space to the river, and a budget of € 2.2 billion was allocated.

The programme, which started in 2007, connects water management with spatial planning. Measures include relocation of dykes to create additional space within the flood plain, lowering the floodplain by excavating sediment, creation of additional flood channels (by-passes or 'Green Rivers'), increasing the depth of flood channels, reducing the height of the groins, and removing obstacles from the floodplain. In the programme, the government and the regions worked together intensively to come up with optimal solutions. Initially, the traditional top-down approach to policy-making resulted in substantial resistance from local inhabitants (Roth and Warner, 2007). This created awareness among policy-makers that a dialogue with inhabitants was of utmost importance and the interaction between professionals and stakeholders gradually shifted from a consultative approach to a real participatory approach in the research and design process of combined regional and sectoral adaptation strategies (Veraart *et al.*, 2010). Through this increased awareness for stakeholder participation even the most extensive and far-reaching projects were implemented successfully with support from local communities. An example is the quayside and river park constructed along the newly created 2 km long side-channel in the river Waal near Nijmegen and Lent. To create the new side-channel the dyke was relocated 350 m inwards at the cost of the village of Lent. Relocating of the dyke and the creation of the side-channel, facilitates a water level reduction of 0.35 m and at the same time resulted in a new river-park where there is more room for water, nature, recreation and municipal activities (Figure 4).

Figure 4. New quayside along the newly created 2 km long side channel in the River Waal near Nijmegen and Lent (photo: J.M. van Loon-Steensma).

In 2016, almost all 34 '*Room for the River*' projects were completed (www.ruimtevoorderivier.nl/english/) and, as a result, the river Rhine can now cope with an extreme discharge of 16,000 m^3 s^{-1}. (Note that this is still lower than the predicted future extreme discharge of 18,000 m^3 s^{-1}). Preliminary results, based on interviews with experts and stakeholders, suggest that a robust, multifunctional dike in comparison to a traditional dike appears to be the more efficient spatial use due to the combination of different functions, a longer-term focus and greater safety (van Loon-Steensma and Vellinga, 2014).

FLOOD RISK ASSESSMENT AND COMMUNICATION

The multi-layer safety approach involves a gradual shift from government to governance in flood protection - turning away from vertical steering mechanisms, such as rules and regulation, towards horizontal steering through networks and systems in which other stakeholders (e.g. citizens, private and non-governmental organizations) have a more prominent role (Veraart *et* *al.*, 2010). Success with this approach requires increased communication of pertinent information so that the multiple stakeholders can fulfil their roles effectively. Generation and accessibility of flood risk assessments is part of this process. A new, so-called, “storyline” approach is used to develop consistent flood risk management strategies and emergency plans (de Bruijn *et al.*, 2016). In this approach, the whole sequence of events during a flood, from the initial rise of the flood threat, the actual flooding up to the recovery of the flood impacts, is analysed for the most critical subsystems (water system and infrastructure), the actors (water managers, local authorities, critical infrastructure operators and inhabitants) and their interactions.

Although the current risk of flooding is low, the consequences of a dyke failure can be disastrous, making it important for the general public and organizations to be aware of the potential risks in their area. While the measures to reduce the effects of flooding, i.e. step 2 and 3 in Figure 2, are vital in the multi-layer safety approach, they will never replace the primary flood protection role of dykes and embankments. The probability of failure of the primary river dykes and embankments, totalling in length about 3,200 km, is small as most of them have been designed and constructed for a frequency of flood occurrence of up to 1/1,250 year (Van Baars and Van Kempen, 2009). However the secondary dykes, built along inland canals to prevent the flooding of the surrounding lands, are often built from peat and have a greater risk of failure, especially during prolonged dry periods in summer when the peat can start to crack due to drought stress in the core of the dyke (Van Baars, 2005). Each province and municipality has the legal obligation to prepare emergency scenario maps for flooding risk as well as other kinds of risk. For each region of the country, risk-assessment maps have been prepared for a number of risks or disasters that can occur, for example explosions, airplane crashes, traffic accidents, fires in buildings or tunnels, and natural fires as well as floods. These risk-assessment maps are available on the internet (http://www.risicokaart.nl/en) and every individual can see whether there is an increased risk in a specific area along with advice about what to do in case of emergency (Figure 5). The user can select the degree of detail, he/she can zoom in up to the level of a municipality, street, company, high risk location, etc., by using the corresponding postal code. These measures to increase awareness of the general public of various risks are based on the EU Flood Risk Directive (http://ec.europa.eu/environment/water/flood_risk/implem.htm).

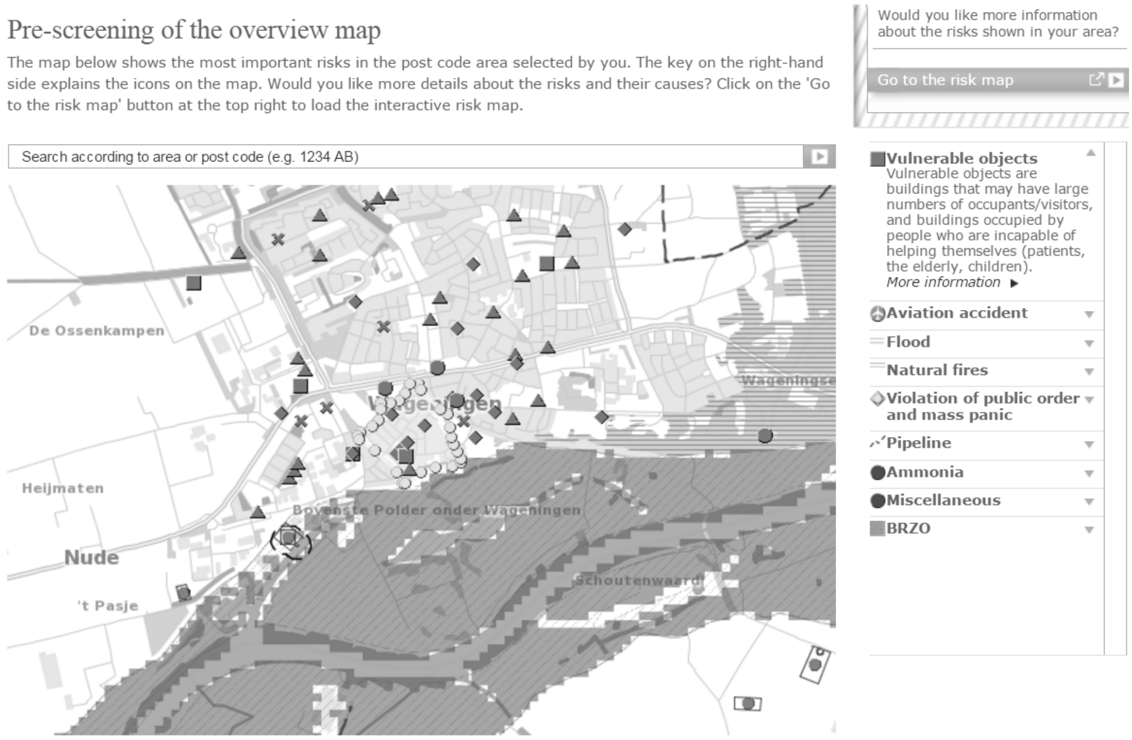

Figure 5 For each area in the Netherlands risk-assessment maps can be consulted on the internet: example of flood-prone areas near Wageningen (http://www.risicokaart.nl/en).

Evacuation has the potential to save lives, but it can be costly with respect to time, money, and credibility. Because the flood-prone areas are so densely populated, a strategy based on preventive and vertical evacuation is needed. The success depends on a combination of the available time, the response of both citizens and authorities and the capacity of the infrastructure (Kolen *et al.*, 2013). A complicating factor is that the Dutch people, although the majority live in flood-prone areas, do not consider flooding to be a risk (Den Besten, 2016). Because they think that the risk of flooding is small, they do not take the emergency advice seriously (Baan and Klijn, 2004). A recent study shows that about 25% of the population will ignore the advice of the local authorities (Figure 6). Because of this apparent sense of security, the consequences of flooding when it does occur will be more severe and more people will be at risk. This example shows that the multi-layer safety approach, in which equal priority is given to all layers (preventive measure, spatial planning, emergency measures) can result in a false sense of security and therefore has its limitations.

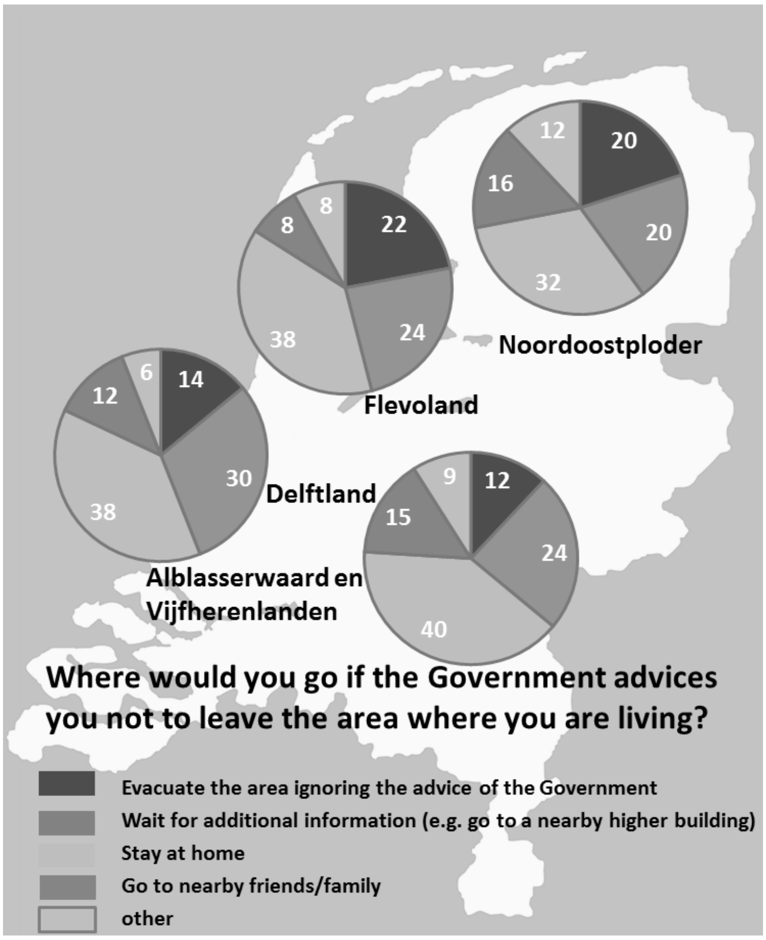

Figure 6 Response of the local population (in %) on an advice of the local government to leave the area where they are living in case of an emergency (Source: University of Twente, Department of Psychology & Communication of Health & Risk, 2009).

INFRASTRUCTURAL CHALLENGES CAUSED BY THE NEVER-ENDING SUBSIDENCE

Constructing water-robust (infra-)structures and buildings, one of the three pillars in the multi-layer safety approach, in a challenge in the flood-prone areas of the Netherlands, where the never-ending process of subsidence has major repercussions on the construction of roads, structures and residential and industrial buildings, i.e. (Figure 7):

- uneven road surfaces result in decreased safety and require more frequent maintenance;
- shallow water tables result in damage to foundations of buildings and structures;
- uneven subsidence results in misalignment of underground power cables, as well as water and gas mains, and reduces the lifespan of sewerage systems;
- subsiding pavements, parking lots, farmyards, compounds and gardens create flooding

problems and reduce the accessibility to homes and offices.

Figure 7 Problems associated with building on peatland, examples from the Netherlands: flooding (left); subsidence of roads (middle), and; subsidence of sewerage mains (right) (Photos: Deltares, 2008).

The challenge is to strive for a balance between water levels that allow optimum land use and water levels that minimise subsidence. Innovative solutions, e.g. floating roads, buildings and structures, buildings on piles, etc., are required to reduce and counterbalance the never-ending subsidence. The investment, operation and maintenance costs depend on the type of underground: on peatlands they are higher than on mineral soils. In a study, the total investment, operation and maintenance costs for the development of a suburb of 3000 houses were calculated for typical land and water conditions in the Netherlands (Fiselier, 2006). Four alternatives were considered, namely a suburb built on: (i) mineral (clay) soil on which a sand layer of 0.5 m was added (a normal practice in the Netherlands to compensate for the initial consolidation), and three alternatives on peat soils, i.e.: (ii) peat without any additional sand supplements; (iii) peat with houses built on the water; (iv) peat on which a sand layer of 0.5 m was added. The results show that the investment costs as well as the costs for operation and maintenance are considerably higher for the suburbs built on peat (Figure 8). The study also shows that building on peat also requires significantly more space (140 ha) than building on clay (120 ha), because of the higher percentage of open water that is needed for storage of rainfall runoff. The difference in costs can be attributed to this larger area, the cost of building floating and/or flood-proof houses, and the higher costs for roads and the bridges that are needed as a result of more open water courses. The effects of climate change, e.g. sea level rise and more intensive rainfall, will further aggravate these associated costs.

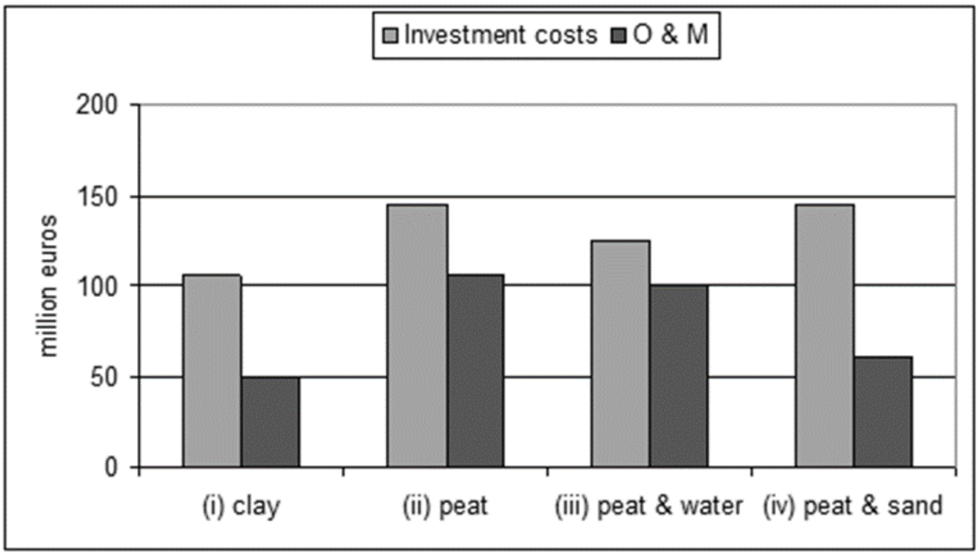

Figure 8 Investment costs and costs for O&M (capitalized costs for 2020) for a suburb built on (i) mineral (clay) soil; (ii) peat soil; (iii) peat soil with floating houses and; (iv) peat with 0.5 m of sand (Fiselier, 2006).

The results of the above mentioned study are in agreement with another study conducted in 54 municipalities in the Netherlands, in which the differences in operation and maintenance costs for municipalities, located on '*poor*' (mainly peat and unripe clay), '*medium*' (mainly clay) and '*good*' (mainly sandy) soils were quantified (Cebeon, 2005). The analysis showed that the costs in the '*poor*' soil municipalities are 19 and 41% higher than the costs for the '*medium*' and '*good*' soil municipalities respectively. A clear implication from these higher costs is that pumped drainage is only feasible for land use with very high rates of return, e.g. horticultural crops, agro-based industries or urbanization. Because pumping becomes more economical if more water storage capacity is created inside an area, this study also suggests that a higher percentage of the land area needs to be open water or wetland. Creating water bodies and wetland areas that are large enough to allow economical pumping can easily take 20 to 30% of the total land area. Both studies make it clear that innovative measure like floating houses, caisson foundations, flexible joints, etc. are required when building on subsidence prone subsoil, especially peat.

Sustainable solutions for permanent structures on these subsiding soils should be based on the principles that the ground pressure of structures should not exceed the bearing capacity of the soil (for loads of relatively short duration) or that the on-going consolidation of the soil layer under these structures is approximately equal to the total, unavoidable, subsidence of the surrounding area. There are several options and methods available to reduce subsidence or to live with it, for example:

- light and buoyant materials such as polypropylene or compressed peat can be used in foundations for structures and roads, or, alternatively, floating structures can be used (Winter *et al.*, 2005);
- forced consolidation by using vertical drain pipes or dewatering drains ;
- reinforced soil foundations using geotextiles, mixing peat with cement or using biotechnology processes;
- flexible connections between cable or sewerage systems and houses, roads and bridges;
- flood-proof foundation and building techniques, i.e. foundations on piles, building on artificial mounds, a method used in the northern parts of the Netherlands for more than one thousand years (Van de Ven, 2004);
- floating houses, floating suburbs and/or floating greenhouses (Woltjer and Al, 2007) (Bakker *et al.*, 2004) (Figure 9).

Figure 9 Smart solutions: floating houses (left); floating suburbs (middle), and; floating greenhouses (courtesy: Dura Vermeer).

ADAPTATION STRATEGIES IN RURAL AREAS

Based on the new *'retention, storage and controlled removal'* drainage strategy (Figure 3), Van de Sandt and Goosen (2010) assessed the required changes in water management approaches across the Netherlands in light of assumed changes in land use and possible strategies for adaptation and/or resilience. To develop scenarios for adaptation, they divided the Netherlands into three hydro-ecological zones, based on the soil type and the elevation with respect to mean sea level (MSL): (i) the man-made polder areas with marine clay soils along the North Sea coast and the former Zuider Sea with elevation below sea level; (ii) the low-lying peat land areas in the west (also below sea level) and north, and; (iii) the sandy and loamy soils areas in the centre, south and east with elevations well above sea level. Each zone has its own land and water characteristics and associated land uses and, based on the predicted land use changes, future water management strategies were developed (Table 1).

Table 1. Adaptation of the water management approaches based on the predicted land use changes in respectively the marine clay areas, peat land areas and sandy soil areas (Van de Sandt and Goosen, 2010).

Land use	Changes in water management approaches based on	Expected change in land use[a]		
		Agriculture	Nature	Recreation
Clay & Sandy areas:				
• High-tech agriculture	Resilience	++	--	+/-
• Large-scale agricultural	Resilience	++	-	-
• Peri-urban multi-functional agriculture	Adaptation	-	++	++
• Rural multi-functional agriculture	Adaptation	--	+	+
Peat lands:				
• Peat lands, vulnerable to subsidence	Adaptation	-	++	+/-
• Peat lands, not vulnerable to subsidence	Resilience	++	-	+

[a] ++ = increase in importance; -- = decrease in importance; +/- = no change in land use

Polders with marine clay soils along the North Sea and former Zuider Sea

The marine clay areas of the Netherlands extend over the entire coastal zone and along the IJsselmeer with some interruption from the western and northern peatland areas. The land is predominantly used for agriculture, but especially around cities other types of land use are developing rapidly, i.e. urbanization, recreation, as well as transportation and industrial infrastructure. Traditionally, water management has been geared to the land use with a high degree of regulation and focus on reducing salinization caused by upward seepage. Drainage systems consist primarily of (pipe) field drains to control the groundwater level in the field. These field systems drain by gravity into open collector drains from which the water is pumped to the main drainage system (Ritzema & Stuyt, 2015). The open collector drains are also used to remove excess surface water. In large parts of the west and the north of the Netherlands, the shallow groundwater is brackish with only thin fresh water lenses (< 2 m) in or just below the root zone. Due to sea level rise, upward seepage of the brackish groundwater will increase in the coming years and thus the total salt flux will as well. This process is called internal salinization. Subsidence in these areas further contributes to this internal salinization. Along the southwest coast of the Netherlands, salt loads are expected to double in the coming years in some parts of the deep and large polders (Oude Essink *et al.*, 2010). In the deep polders further inland, autonomous up coning of deeper and more saline groundwater will also increase salt loads. To combat internal salinization the water management system is flushed with fresh water from the IJsselmeer and the major rivers. This flushing is not efficient because the water management system is wide-spread, and fine-meshed with many dead-end loops: subsequently only a small percentage of the total amount of the water that flows to the sea is used for flushing and irrigation. Rainwater is an untapped or underutilized source of fresh water that does not need to be pumped through the existing water management system. Therefore, the adaptation measures in this zone, e.g. controlled drainage, aim to increase the storage of excess rainwater in the soil profile, and to use this excess water to leach salts.

Low-lying peat areas in the western part of the Netherlands

Peat lands are characteristic for the Dutch landscape and mainly used as grassland for pasture. There are two regions with peat; the western peatland region (the '*Green Heart'* area between the major cities of Amsterdam, The Hague, Rotterdam and Utrecht) and the northern peatland region (Friesland and North-West Overijssel). The western peatland area is mainly used as grassland for dairy farming, but it also has a strong recreation function for the inhabitants of the four major cities surrounding the '*Green Heart'* area. In the northern peatland area the dominant use is agricultural production, although there are also lakes and marshes set aside for nature and recreation. Traditionally these peat lands are drained by an open drainage system: shallow field drains carry the surface water to open collector drains, and water levels are controlled by gates and/or pumps. Drainage plays a major role in the never-ending process of oxidation, resulting in subsidence and greenhouse gas emissions. To reduce subsidence, surface water levels in the traditionally used open drainage system in peatlands are kept shallow, between 30 and 60 cm below ground level. This often results in waterlogged conditions in winter when the drainage capacity is not sufficient to remove all the excess water, but it can also lead to low groundwater levels during dry periods in summer when the recharge of water from the open drains is insufficient to replenish the groundwater used by the crop. To cope with the impacts of climate change, the concept of submerged subsurface drainage systems has been investigated with the aim of gaining better control of the groundwater level in periods of excess rainfall and to allow sub-irrigation during dry summer periods. Combining land use functions with ecosystem services can reduce the risk of flooding considerably (Ritzema *et al.*, 2016).

Sandy and loamy soil areas in the south and east of the Netherlands

The Netherlands has three large sandy areas: (i) in the middle (Veluwe); (ii) in the east (Drente, Overijssel and East Gelderland) and; (iii) in the south (Brabant and Limburg). Characteristic elements are sandy plateaus intersected by sand and peat stream valleys. Originally, large parts of the land in Drente and Brabant were covered with peat that, over the last two centuries, was excavated and used for fuel. This has resulted in relatively flat areas with mainly sandy soils. Land use is diverse: varying between multifunctional peri-urban regions and rural (small-scale agriculture, forest, nature) areas with high cultural value in Overijssel, East Gelderland and Limburg to large-scale agriculture in Drente and Brabant. The hydrology of these areas is characterized by infiltration areas and seepage areas. The higher sandy areas act as infiltration areas, where the precipitation surplus percolates to the groundwater that re-surfaces as seepage in the valleys between these higher areas. Many streams have been straightened to improve drainage. However that has resulted in excessive drainage upstream and flooding downstream. Agriculture is mainly rain fed, sometimes supplemented by irrigation with groundwater. Changing rainfall patterns not only increase the risk of flooding during extreme rainfall events but also lengthen and intensify periods of precipitation deficit during the growing season. To retain water upstream and thus to reduce water shortage and down-stream flooding, real-time control structures can be installed to utilize the storage that is available in the canals and streams in the upstream part of a (sub)catchment (Van Overloop, 2006).

For all three hydro-ecological zones, controlled drainage shows promise as a tool for improving the balance between various types of land use, not only between differing types of agricultural use, but also between agriculture and nature, an often delicate balance between the conflicting drainage requirements of these two land uses (Ritzema *et al.*, 2016). In the light of the predicted changes in rainfall patterns and intensities, a system that combines controlled drainage with weather forecasting also looks promising, both for the water manager and the farmers: for the water managers to reduce peak discharges after heavy rainfall events and for farmers to restrict outflow when a drought period is predicted. Stijnen *et al.* (2014) have studied the robustness of the Dutch polder approach, which refers to the drainage and flood protection of low-lying areas by means of pumps, canals and flood defences. They concluded that there are neither technical nor economic reasons to question the future effectiveness of this approach, although societal acceptance and conflicting interests with other functions are critical factors for its success. It should also be realized that, while the evidence clearly shows that controlled drainage has many benefits compared to traditional un-controlled drainage systems, controlled drainage solutions are very location-specific, and that tailor-made solutions are a prerequisite for success (Ritzema and Stuyt, 2015).

CONCLUSION

Climate change is expected to have far-reaching effects on low-lying, densely populated, delta areas like the Netherlands. In addition, there is often significant population and economic growth expected in these delta areas. To cope with the possible impacts of these developments, the Government of the Netherlands has reformulated their policies for flood protection and water management. Traditionally after each and every disaster dykes and embankments were heightened and strengthened and the capacity of the drainage system was enlarged. To end this vicious cycle of acting after a disaster, a paradigm shift in flood risk and water management has been adopted. Instead of focussing only on prevention of flooding, the new standards also take the potential impacts and risks of flooding into account. This multi-layer approach is based on three pillars: (i) preventive measures to strengthening the flood protection and water management systems to protect vital and vulnerable infrastructure; (ii) spatial planning to reduce the possible impacts of flooding; (iii) disaster management to prevent social disruption caused by this flooding. Water management is also changing to a more adaptive and participatory approach in which, instead of simply increasing drainage and pumping capacity time after time, the focus has shifted to controlled drainage with the aim to get a better control over the drain discharges and water levels than simply pump out the water. The challenge is to strive for a balance between water levels that allow optimum land use and water levels that minimise subsidence. Innovative solutions, e.g. floating roads, buildings and structures, buildings on piles, etc., are developed to reduce and counterbalance the never-ending subsidence. Although the challenges are clear, addressing them effectively will take time. In The Netherlands and other countries in Northern Europe, this process of optimisation, has been going on for centuries and will continue to do so. It will only be successful here and elsewhere in the world if the principles and practices of sustainable '*wise use*', especially with respect to flood protection, hydrology and water management, are taken into account.

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