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Climate adaptive urban planning and design with water in Dutch polders

T. Schuetze and L. Chelleri

ABSTRACT

The existing water management in Dutch polders is based on independent water systems for each polder. These are featuring artificial stabilized ground and surface water levels. As a result of the local climate the water levels in the polders are not continuously at a constant level. To maintain a stable water table in the polders, the surplus of relatively clean rainwater has to be pumped away during the cold seasons into canals or rivers, which are located on a higher level. During the summer relatively polluted water from these waterways is led into the polders to top up the declining water levels. This procedure leads to various problems regarding water quantity and water quality. The described existing system is not adaptable to climate change and includes the risk of flooding, particularly from torrential rain. Therefore it is crucial to develop, preferably self-sufficient, rainwater management systems in the polders. They should allow the fluctuation of the water levels inside the polders for seasonal storage and flood control. The described concept is adopted in the present water policy in the Netherlands as well as in research and recent urban development projects in Dutch polders.

Key words | climate adaptability, Netherlands, polders, rainwater management, urban design

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INTRODUCTION

The Netherlands has more than 50% of its territory below sea level. In fact, polders are embanked low lands with different characteristics. In some cases polders are even reclaimed from water areas, thanks to the Dutch worldwide recognized capability of inland and coastal water management. At the same time, the increasing development of housing, infrastructures, industry and agriculture have been increasing the human pressures over the fragile deltaic system. Large parts of the surface soil in Holland consisted naturally of thick layers of peat, a material that was traditionally cut and used as fuel, and has therefore been exploited. The biggest environmental changes from sinking peat bogs occurred in the 14th and 16th century ([Van Dam Petra 2001](#)) while the resultant lowlands were turned into lakes as they accumulated rain and groundwater. These reclaimed wetlands were not suitable for farming and also caused flood threats to the neighbouring cities (like the Haarlemmermeer for Amsterdam). Therefore, a complex strategy had characterized the last century of water management in the Netherlands. The technocratic–scientific regime was characterized mainly by measures such as the raising of existing,

and construction of new, dikes as well as the drainage and pumping of surplus water from lowlands. Such strategies have not resulted in sustainable water systems as many calamities have occurred and a transition in those models is required ([Van der Brugge et al. 2005](#)). The study of the Dutch water management and the relative past and present territorial planning strategies help to clarify why in recent times there is a need for a new climate adaptive design of polder systems. We can recognize in five steps the historical background of the territorial configuration and relative water management, from a ‘natural’ to ‘manipulative’ practices ([Figure 1](#)).

From the natural landscape configuration (initial phase 1), the urban ‘natural’ water management (represented by the phase 2) in Holland was practiced until the year 1,000 AD and was characterized by taking advantage of the protection from the existing territorial topography and dealing with minimal interventions in the natural water system. In fact human settlements (such as The Hague) were located on the top of naturally elevated grounds, for example dunes or hills, to facilitate the drainage of rainfall and the

Figure 1 | The phases of water management in Dutch polders (After: Hooimeijer *et al.* 2005).

protection from rivers or tidal flooding. A third period can be recognized as ‘defensive’ water management, which lasted until the 15th century. The passive draining and flood protection of cities (such as Dordrecht, Leiden and Amsterdam) was achieved by manmade structures, like dikes and dams. The territory morphology was not changed so much until this point. Peats and wetlands still constituted the main landscape, while the human settlements were built and protected from the threats of flooding from the sea and rivers in a defensive way. A shift in model identified within the fourth, so-called ‘offensive’ water management period, which lasted approximately until the middle of the 19th century. It was characterized by the intensive drainage of large wetland areas, for urban and agricultural purposes (and to protect the neighbouring cities from flood threats) and this was facilitated by the invention of the windmill.

The last ‘manipulative’ water management phase started in the middle of the 19th century and was enabled by technical inventions, like the steam engine and construction technologies in the framework of the so-called ‘industrial revolution’. Effective pumping technologies with previously unknown capacities facilitated large-scale interventions, like the drainage of big lakes for agricultural and urban purposes. One of the biggest and most famous examples is the Haarlemmermeer, which consisted of a lake that was drained and transformed into a polder in 1852. Today, the area houses amongst others Schiphol international airport and one of the fastest growing urban developments in the Netherlands. Another large-scale plan developed in this

period is the water project for Rotterdam, which was adopted by the municipality in 1854.

Figure 1 provides a schematic overview of the development of the Dutch lowlands from the year zero until the year 2000, synthesizing the five historical main water management phases. Contemporary water management systems in the Netherlands are generally still based on the principles of the last manipulative water management period, and the polders are still the resilient Dutch territorial unite of any anthropologic development. In fact, as represented in Figure 2, polders are embanked lowlands, which are equipped with individual area wide water supply and drainage systems. Traditionally, these consisted of open ditches. Generally, the ground and surface water levels in polders are artificially stabilized to facilitate

Figure 2 | Perspective section of a polder with typical water management elements: drainage and water supply canals in a polder are connected to a ‘boezem’ via a pumping station. The intrusion of saltwater from the sea in the groundwater of the polder is prevented by freshwater supply and infiltration between the polder and the dunes (Vlies *et al.* 2006).

urban and agricultural developments and uses. The enclosing dikes aim to protect the lowland from flooding by the surrounding and elevated rivers or canals (Dutch: 'boezems'), which are connected to the hinterland and empty to the sea. These boezems are connected to polders via pumping stations. On the one hand these stations can discharge surplus drainage water from polders to canals or rivers to avoid flooding. On the other hand they can supply freshwater from these water bodies to polders to avoid drought. Boezems have therefore two important functions for polders: freshwater supply, as well as drainage and discharge of surplus water to the sea.

The natural water balance and available water quantity in polders is influenced mainly by climatic factors (such as precipitation and evaporation) as well upward seepage from adjacent water bodies, such as rivers. Upward seepage from the sea (saltwater) as well as from rivers and boezems (freshwater) can influence not only the water quantity but also negatively impact the water quality in the adjacent polder areas. Dependent on the soil types and the water pressure, significant amounts of water can infiltrate the polders. The infiltrated water contributes to water surplus and a declining surface water quality in the affected areas. Investigations regarding the effects of upward seepage of groundwater originating from rivers Rhine and Meuse found, for example, positive correlations with nitrate, potassium, sodium and chloride (Vermonden *et al.* 2009). The effects of groundwater seepage originating from large rivers in lowlands on the chemistry of urban water systems should therefore be taken into account for the improvement of the water quality status in polders.

Saltwater intrusion in polders through seepage of seawater is generally prevented by naturally or artificially recharged freshwater aquifers, which are located between polders and the sea (refer to Figure 2). However, the seepage of freshwater through salty soils can lead to salinisation in polders. Additionally, the intrusion of saltwater in rivers during high tides and/or periods with low river discharges causes problems for the freshwater supply of polders in the coastal areas. The effects of climate change such as the rising sea level and more frequent low river discharges during periods of drought (mainly during summer months) allow the salty seawater to flow further inland. The resulting salinisation of the river water in the Rhine-Meuse estuary therefore causes growing problems for the freshwater supply [for instance for drinking water production and irrigation of regional agriculture (Rijkswaterstaat 2007)].

Urban development in polders generally deteriorates the described situation due to sealing of grounds as well as

reducing the evaporation and the potential storage areas for rainwater (if decentralized water management solutions are not applied and integrated in the urban system). Nevertheless, the specific regional climate in the Netherlands is one of the most important basic conditions for the water management in Dutch polders. It is generally characterized by quite equally distributed rainfall over the year and periods with high and low evaporation. During the cold months, between September and March, the average potential evaporation is lower than the rainfall. Therefore, these periods generally feature a positive water balance. During the warm months, between April and August, the average potential evaporation exceeds the rainfall. Therefore, these periods generally feature a negative water balance [Figure 3(a)]. To keep a stable water table in the polders, a surplus of relatively clean rainwater has therefore to be pumped away during the cold seasons in case of heavy rainfall into canals or rivers, which are located on a higher level than the polders. During the warmer months and the agricultural growth period (from April to September) relatively polluted water from the waterways has to be led into the polders to top up the declining water levels. These are caused by higher water demand for agricultural activities in polders as well as by the high evaporation rates, which generally exceed the precipitation rates during that period. This procedure leads to multiple problems regarding water quantity and water quality in polders, particularly in the framework of the occurring effects of climate change.

In fact, the described existing system is not adaptable to climate change because heavy rainfall cannot be managed well. The increased pumping of surplus water from polders, during extreme precipitation events (or in case of rainfall exceeding the evaporation rates) includes the risk of flooding in polders, due to limited pumping capacity, and also the risk of overflows of the entire drainage canal systems in downstream areas.

For instance, the standard drainage capacity in the Dutch polder landscapes is calculated to remove 14 mm rainfall per 24 hours. In September 1998 [Figures 3(b) and 3(c)] in some areas 130 mm fell in 24 hours, exceeding the drainage capacity and leading to the flooding of large agricultural and urban areas. Since then comparable scenarios have occurred quite regularly in different regions of the country, causing damage running into several billions of Euros (Vlies *et al.* 2006).

Due to global warming it is not only expected that the sea level will rise, but also that floods by storm tides and extreme precipitation events, with a return period of 100 years, may occur more often in the future. In contrast,

Figure 3 | (a) Monthly balance of averaged precipitation and evaporation in the Netherlands from 1971 to 2000 (Schuetze 2008). (b) Flooding in September 1998 (Vlies *et al.* 2006). (c) Monthly average precipitation in the Netherlands from 1971 to 2000 (black columns) compared with the two extreme years 1998 and 2003 (After: KNMI 2008, 2010).

extreme droughts, causing water quality and quantity problems, which also have multiple effects on eco- and infrastructure systems, are expected to occur more often (Intergovernmental Panel on Climate Change 2007). A climate adaptive water management strategy therefore requires the development of preferably sustainable and self-sufficient systems in polders, which can be based on decentralized rainwater management. Such systems should avoid the drainage and discharge of clean rainwater and should allow its seasonal storage, as well as flood control during extreme precipitation events. The working principles of such systems and the consequences for climate adaptive urban design will be further discussed in the subsequent sections of this paper.

METHODS

This article focuses on the latest insight from the authors' own investigation into the fluctuation and circulation water management models in relation to the Netherlands polders. The presented case studies act as 'snapshots' of the Dutch polders' current situation and challenges, from the latest water management theories to some detailed examples. The paper navigates along the most recent timeline of transition toward a new self-sufficient polder model and configuration. A framework of the historical development of water management in Dutch polders is presented to better introduce the latest approach to manipulative and adaptive water

management. This article aims to identify, examine and prove the effectiveness of some new models of adaptive water management facing the latest challenges identified for the future configuration of the Dutch territories and cities. Mainly based on the retention, circulation and fluctuation models, the insights from case studies serve to prove the applicability of those models both for redesigning the existing or planning new urban settlement in Dutch polders.

Quantitative data, about the average and extreme precipitation, evaporation and flooding in the Netherlands was collected, while at the same time as far as possible qualitative analysis of approved water management concepts was made based on recent research findings and the author's own investigations. Finally the concept of adaptive (and self-sufficient) polder water management emerges as the necessary next step for the next transition in Dutch water management law and the decentralized rainwater management. Different urban areas, infrastructures and the most recent projects were examined in terms of the applicability of an integrated way forward for a new resilient and adaptive polder structure.

RESULTS AND DISCUSSION

To cope with the rising problems of water management in the Netherlands, a team of experts, the 'Dutch Advisory Committee on Water Management in the 21st Century' was asked by the government to develop strategies and

guidelines for sustainable Dutch water management. One of the outcomes was the ‘three-step strategy’ paper (Ministry of Transport, Public Works and Water Management 2000), enacted by the government in a new approach to ensure safety and reduce water related problems in the 21st century. The guideline that has been introduced in the Netherlands is focused on new urban developments. The strategy is based on the concept that by the introduction of self-sufficient water management systems, which reduce the discharge of rainwater and the inlet of river or canal water to the greatest possible degree, rainwater management problems should not be shifted to other areas. This aim can be achieved by following the ‘three-step strategy’ (Van Stokkom & Smits 2002a, b):

- First priority is for rainwater collection & retention
- Second priority is for rainwater retention & storage
- Last priority is for the drainage of the surplus water

Collection, and respectively retention, includes the separation of rainwater from the sewage stream at the source. The retention can be realized either by natural methods (for example by green roofs or wetlands) or technical (for instance by tanks). Retention with nature-orientated systems allows multifunctional use of the retention areas and technical measures can be realized in a way that they are not limiting the use of buildings and properties. The measures are feasible in new urban developments as well as in remodelling projects and are applicable on different scales, such as building, property and city levels (Schuetze 2005). The

retention of rainwater with open water bodies may limit the use of properties and buildings, but due to the high groundwater levels, close to the ground surface, and the impervious soils, the nature-orientated underground retention and infiltration of rainwater is mainly not, or only to a very limited degree, possible in Dutch polders. Therefore, such measures can generally only be realized in open water bodies. Accordingly, and based on guidelines for future water management in the Netherlands as well as the ‘three-step strategy’, some district water boards insist that 10% of the land surface area of new developments consist of open water bodies (Tjallingii 2008).

An example for such a concept, realized in the framework of new urban developments in formerly agriculturally used polders between the cities Delft and Den-Haag, is the area ‘Wateringse Veld’. The new developments are located in polders, which are still separated by dikes, some of them with roads [Figure 4(a)]. In fact the surface and groundwater levels in the polders have different heights and are connected with each other by overflows, which can be used to control the water flow from higher to lower polders. In some areas the rainwater from roofs and traffic areas is collected in open drains and discharged through sand filters directly into the open water bodies.

The urban design with open water bodies is relatively easy to realize in new development areas, but it is more difficult in existing cities. However, there are also numerous projects that focus on the integration of open water bodies in urban renewal projects to enhance the climate

Figure 4 | (a) Impression of the new urban developments in ‘Wateringse Veld’ (Schuetze 2007). (b) Past, present and future Breda harbour (Municipality of Breda 2008). (c) Impression of a canal, which is part of a circulation system in a housing estate in Delft (Schuetze 2007).

adaptability of existing Dutch polder cities. In historical cities, the restoration of old water bodies is used for issues of water management and for the enhancement of the living environment. Actual examples of projects are the restoration of the old harbour in Breda [Figure 4(b)] and the restoration of the old ring-ditch structure in Utrecht (Toorn Vrijthoff & Heurkens 2008). The planned projects are providing on the one hand more room to the river and therefore are contributing to the flood protection of downstream areas. On the other hand, they are allowing the retention of rainwater runoff. However, additional measures at the source (for example on building and property levels) are required for the disconnection of rainwater drainage from the existing domestic waste water systems.

The new climate adaptive and environmentally sound water management approach in Dutch polders avoids the discharge of the surplus water from the polders as well as the inlet of polluted water from canals and rivers to the polders to the greatest possible degree. Nevertheless, a further step towards the resilience of those systems has to be promoted to address the future challenges in terms of climate change and growing urban population trends. Consequently the design of desirably self-sufficient water systems for each polder is required. A first step towards this new polder configuration is that the retention of clean rainwater has to be facilitated over dry and wet periods of a year by the so-called 'seasonal storage', as well as for extreme precipitation events by so-called 'peak storage'. The first problem faced in such practices is to keep a good water quality of rainwater which is collected in open water bodies and kept seasonally in closed systems. However, preliminary results suggest that the water can be circulated through a pond and ditch system with aquatic plants, which contribute to the purification of the water (for example phragmites). A guiding model for the design of such a system is the so-called 'circulation model' (Tjallingii 1996). Figure 4(c) shows a canal, which flows through a housing estate in Delft, where such a system has been constructed in the framework of a new urban development.

Another basic guiding model for the design of independent and self sufficient rainwater management systems is the so-called 'fluctuation model', which is based on the concept of the seasonal and peak storage of rainwater. It requires fluctuation in water levels due to seasonal variations in evaporation and precipitation, which affect the water quantity in open water reservoirs. In Figure 5 the average monthly rainfall and evaporation in millimetres over the annual profile in the Netherlands is displayed. It is clear

Figure 5 | Annual profile of average monthly rainfall and evaporation in mm (1971–2000) in the Netherlands (Schuetze 2008).

that the rainfall exceeds the evaporation losses during the cold months (the total surplus is 313 mm) and that the evaporation losses exceed the rainfall during the warm months (the total deficit is 122 mm). According to this balance the water level in a closed water system would decline in the summer, while it would rise in the winter accordingly.

However, the total average annual rainfall (755 mm) exceeds the total average annual evaporation (563 mm) by 192 mm. Furthermore, the average precipitation deficit during the warm months (from April to September) exceeds in more than 50% of the years the average value in the Netherlands. In 45% of the years it is up to approximately 280 mm, while in 5% of the years it is greater than this. The record year was in 1976, when an average precipitation deficit of approx. 330 mm was measured during that period (KNMI 2008). Accordingly, projects that are based on 'fluctuation models' should facilitate the storage of more than the average precipitation deficit of 122 mm and include also a sufficient 'peak storage' volume for heavy rainfall. Presently systems are designed in the Netherlands for example with a storage volume of 180 L/m² rural and/or urban polder area.

The required fluctuation of the water level is dependent on the available water area in relation to the catchment area. According to a simplified calculation model and based on the assumption that 100% of the water area requires a fluctuation of approximately 18 cm, an urban area, which has a portion of 25% open water area, requires approximately 72 cm fluctuation, and an urban area, which has a portion of 10% water area, requires approximately 180 cm fluctuation. These assumptions are based on the average rainfall and precipitation values and do not take into account the possible storage capacities of soils.

A recently built example, where a combination of measures for retention, storage, circulation and fluctuation

of collected rainwater has been realized, is the 'City of the Sun' in Heerhugowaard, near Alkmaar in North Holland. Approximately 25% (75 ha) of the total city area is covered with water, which is part of the recreational area (177 ha) and the building area (120 ha), which comprises 2,900 dwellings. The city is equipped with a closed surface water system, which should mainly be fed by rainwater from the development area. Furthermore, the discharge and the inlet of water, in the cases of water surplus and scarcity, are avoided. The 'seasonal' and 'peak' storage of the total rainfall in the area has been facilitated by the construction of an open water system with a fluctuation between maximum and minimum water level of approximately 70 cm per year.

Figure 6(a) shows the sitemap of the development area, which has been surrounded by a dike and built on top of the existing polder. It is important to notice that the new 'elevated' polder city with its self-sufficient water system is therefore not negatively affected by upward seepages. Any surplus of water occurring in the 'City of the Sun' can be easily discharged to surrounding drainage canals via gravity without any pumping effort.

In the case of water deficit in the city's system, for example in the case of extreme droughts, water can be pumped into the polder from a bypassing canal. However, that water has to be purified before it is added to the city's water system, due to the comparable bad water quality in the external drainage canals (boezems). In addition to the treatment by artificially constructed wetlands, the canal water can be treated by chemical means, particularly to

remove particles and nutrients. The 'circulation system' of the City of the Sun, is aimed at improving the open water quality during seasonal storage. The system is based on an anti-clockwise circulation and nature-orientated purification of the open water which consists of collected rainwater. All sections of the water system are designed for multiple functions but have specific focuses. The primary function of the wetland park (the so-called 'lunapark') which is located in the south-western part of the development area [see Figures 6(a) and 6(b)] is the intensive purification of water, but it serves also as a recreational area. The other water bodies have primary storage and recreational functions (particularly the north-eastern part with beach, bathing and water skiing facilities), but they also contribute to the purification and maintenance of a good surface water quality [Figure 6(c)].

For the design of the buildings, which must be adaptable to the fluctuating water levels, there are various options. In the City of the Sun, buildings and urban infrastructure systems are constructed in conventional way, but the distance between the maximum expected water level and the ground level of the developed area is high enough to prevent damages by extreme precipitation events and rising surface water levels [Figure 6(c)]. Examples for other solutions are, for instance. The building of the 'Aluminium Centre' in Houten near Utrecht, which is elevated on piles above the water, with the advantage that the space below the buildings can be used for the creation of open water bodies and fluctuation of water levels (De Haas 2000). Another project, also with elevated buildings on piles, is designed for the domestic

Figure 6 | (a) Site plan of the City of the Sun (Hoogheemraadschap Hollands Noorderkwartier 2005). (b) Constructed wetlands of the City of the Sun 'lunapark' used both for intensive purification of surface water and recreational uses (Schuetze 2010). (c) Clearly visible in the urban design with water the sufficient freeboard for the fluctuation of the water level in the city of the Sun (Schuetze 2010).

development 'Plan Tij' in Dordrecht, in a water area, which is connected to the river Maas (Klunder Architecten 2008). Hence, the area is unaffected by fluctuations of the water level in the river. For holiday houses in Maasbommel, located in a branch of the river Maas, two different versions have been developed to allow the adaptability to fluctuating water levels, an elevated version at the riverside and a floating version. New urban developments on IJburg, an artificially created island in the urban fringe of Amsterdam, also have areas with floating buildings. A floating information centre was located in IJburg (Zaaijer 2001) during the development phase and was shipped to the harbour area of Amsterdam in 2010, another example of such constructions. Also in Almere, a city located close to Amsterdam, you can find floating and elevated domestic buildings.

CONCLUSION AND OUTLOOK

Research and case studies illustrate that the climate adaptive design with water in Dutch polders is not only feasible, and already practiced in numerous new urban developments, but also offers significant advantages compared with traditional urban development projects and water management systems. However, there is urgent need to enhance the climate adaptability and flood resistance of existing urban areas, in cities such as Rotterdam and Amsterdam. According to the 'three-step strategy', it is particularly crucial to develop plans for the implementation of open water bodies for rainwater retention. While this is widely accepted and addressed in new urban developments, it is so far barely practiced in remodelling projects. Universities and municipalities are cooperating in the development of master plans and strategies for the future climate adaptive development and redevelopment, also of existing urban areas. Due to the high liability to flood (by extreme precipitation events as well as sea and river floods), the sustainable and climate adaptive design with water has a high priority on the political agenda in the Netherlands. Therefore the development and implementation of new innovative and practice orientated concepts and systems in cooperation with the private and public sector universities, municipalities and companies is generally supported. For the future, more space for the realization of pilot projects will be provided (Programmadirectie Kennis en Innovatie 2008). However, still a lot of effort needs to be made to turn these plans and visions into practice, particularly in existing urban development areas, for which no requirements for the implementation of rainwater retention

areas exist to date. The extension of existing guidelines for new development to redevelopment areas could play an important role in this regard, and for the transition from manipulative to adaptive water management, based on the retention, circulation and fluctuation models, which effectiveness have been proved in the framework of realized projects.

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