# The climate barge
## Heritage and climate adaptation in the Dutch province of South-Holland

Mostert, Erik

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# THE CLIMATE BARGE

## Heritage and climate adaptation in the Dutch province of South-Holland

E. Mostert

TU Delft

**COLOFON**

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Author: Erik Mostert, with contributions by Esmee Kuit, Coen Kramer, Fransje Hooimeijer, Olivier Hoes, Pieter-Jan Hofman and Max Hofman

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# Summary

In the project *Heritage uncovered; Tow barge canals in a water management context*, the future value of tow barge canals for climate adaptation has been studied. The project focused on the area between the cities Leiden, The Hague, Delft, Rotterdam and Gouda, with a surface area of $km^2$, and the tow barge canals the Vliet, the Schie, the Gouwe and the Old Rhine. Until 900 CE the areas was mostly peat swamp. Since then, it has been drained for agriculture. This has resulted in economic growth and the development of cities in the 13th Century. A side effect of drainage was land subsidence. In addition, peat was mined to supply the cities with fuel. To limit waterlogging, large drainage canals were dug, such as the Vliet and the Schie. In the 17th Century, many of these were modified to function as tow barge canals connecting the major cities.

It is expected that the water management challenges in the area will increase as a result of climate change. According to the climate scenarios for 2100 of the Royal Meteorological Institute, both heavy rainstorms and periods without any rainfall will become more common. On top of this, there are plans to build many new houses.

To prevent an increase in flood and drought problems, more temporary water storage can be created, but no less than 34 mln $m^3$ of additional storage would be needed. 7.5 mln $m^3$ additional storage can be created in the different polders, primarily to cope with peak rainfall events, while east of the town of Zoetermeer a new lake with 26.5 mln $m^3$ of temporary storage can be created to supply water in drought periods, called the Bent lake (*Bentmeer*). Assuming 2 m difference between the highest and the lowest water level, the Bent lake would need to have a surface area of 13.3 $km^2$. It can offer excellent opportunities for recreation and nature.

To transport water in and out of the Bent lake, a connection to the Rotte river in the south and the Old Rhine (*Oude Rijn*) in the north has to be made. This would restore an old shipping route. For the connection to the Old Rhine three options have been explored and for one of these a spatial plan has been made. In this option the Bent lake is connected to the existing Benthuizer canal (*Benthuizervaart*) and the Benthuizer canal is connected via a new canal to the existing Hoogeveense canal (*Hoogeveense vaart*), (see figures 15 and 16). Along parts of the new canal futuristic "green" appartements will be built with a view either on the canal or over the surrounding polders. To limit height differences for boating, the new canal will be constructed above the level of the polder. The new apartment buildings along the canal will also be built at a higher level, which will make them less vulnerable to flooding (see figure 1, next page).

In all options the old tow barge canals are essential for transporting water to and from the Bent lake and discharging excess water onto the main rivers and the North Sea. In addition, they are a good entry point for telling the history of the landscape and reflecting on possible futures. It is proposed to construct a tow path along the new canal and make a replica of an original tow barge. This barge will be called the "Climate Barge" (*Klimaatschuit*) and can be used as a floating exhibition space and a location for future discussions.

The proposals in this report have not yet been developed in detail and the future is still very uncertain. Yet, we cannot wait until there is certainty. If sooner or later large-scale temporary water storage in this part of the country will be needed, space for this has to be reserved quite soon. The costs will be high, but the costs of inaction will be high too. And it offers new opportunities.


**Figure 1**: Impression of the study area with the proposed Bent lake and the restored Hoogeveense canal. Rotterdam is in the south, Leiden in the north, The Hague and Delft in the west, Gouda in the east and Zoetermeer in the centre.

# 1. Introduction

Heritage can be defined as material and immaterial remains from the past that have value for the present and the future.[1] Heritage can have an economic value, for instance for the tourist industry.[2] It can also have a functional value. Many old dykes still protect against flooding, many historic houses are still inhabitable, and many historical techniques and solutions may help to solve current problems.[3] And thirdly, heritage has an important socio-cultural value. It is a starting point for telling stories how past generations interacted with each other and their environment and thus shaped their environment.[4] It can also be a source of national and regional identity and pride. [5] It can unite, but when certain groups are excluded from "our" history and the dark pages of history are glossed over or, conversely, when history is reduced to these dark pages, it can also separate.[6]

In this report the future value of one specific type of heritage is central: tow barge canals.[7] Many tow barge canals were created in the 17th Century by constructing a tow path along an existing waterway and making other adjustments to allow regular public transport by tow barge. The waterways themselves were natural, such as the Old Rhine, or had been dug to improve drainage of the area, such as the Schie and the Vliet. Other tow barge canals were dug specifically as tow barge canals, such as the tow barge canal between Leiden and Haarlem.

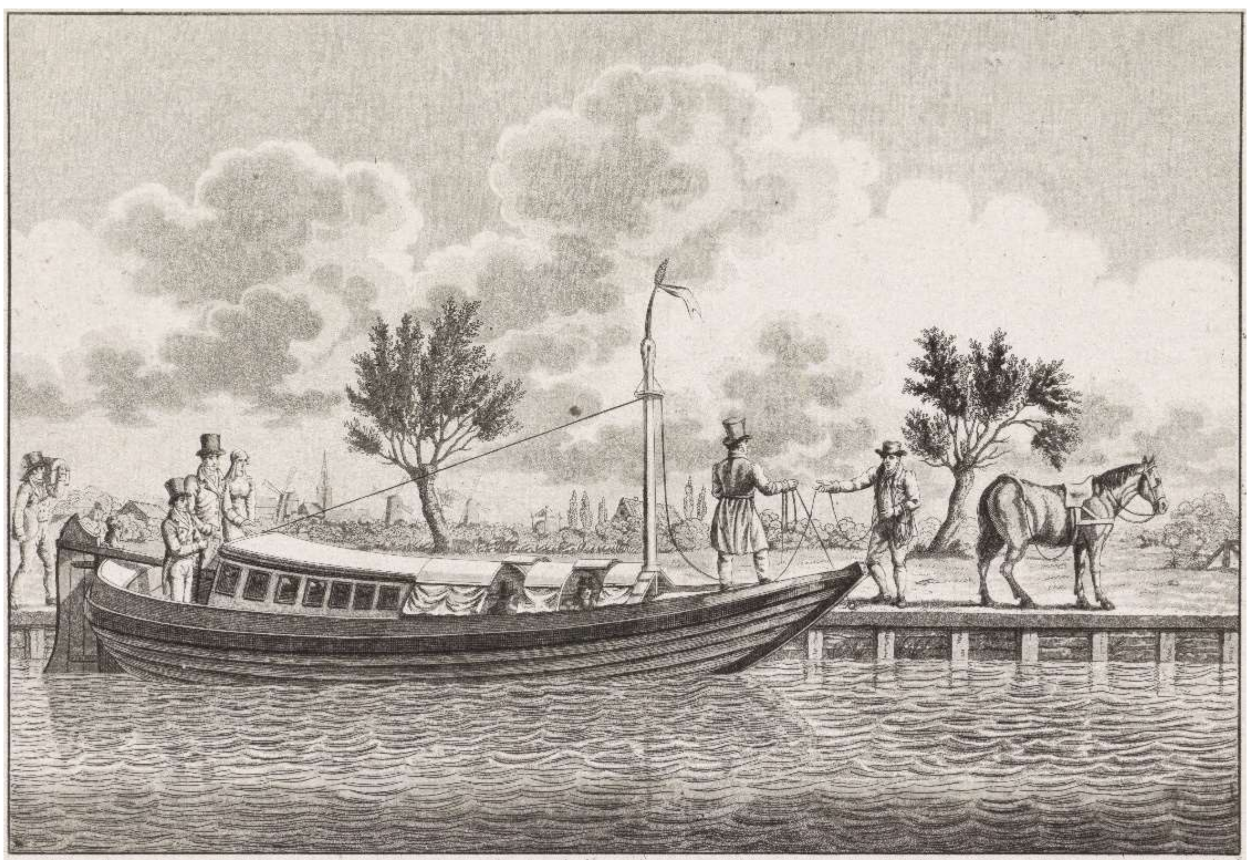

**Figure 2**: Tow barge circa 1830 (Karl-Christiaan Fuchs, 1825-1835, Rijksmuseum Amsterdam)

In the middle of the 19th Century tow barges were replaced by the new railways, which were much quicker and not more expensive.[8] The tow barge canals themselves, however, have not disappeared. They are still essential for water supply and drainage and are still used for shipping and boating. In addition, they have a significant landscape value, recreational value and cultural-historical value.

This report focuses on the Vliet and the Schie and their hinterland onto the Hollandse IJssel and the Gouwe in the east. The northern border is the Old Rhine and the southern border the New Meuse (*Nieuwe Maas*). Apart from the New Meuse and the Hollandse IJssel, all these waters were tow barge canals (figure 3 and 4). The total surface area is about 500 km$^2$. As a result of climate change and land subsidence, flooding and drought problems in this area will increase. At the same time there are plans to build 342.700 new houses in the province of South-Holland until 2042, including many in the study area.[9]

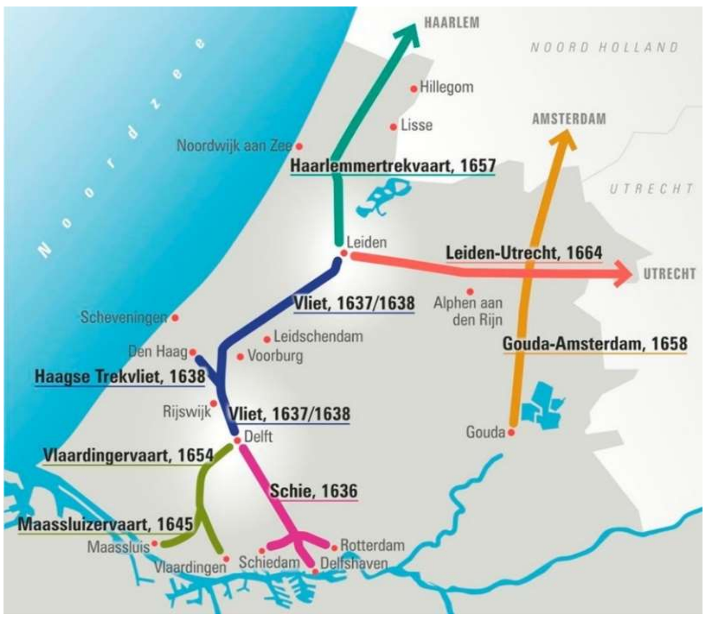


**Figure 3**: Tow barge canals in the province of South-Holland. The study are is between the Vliet and the Schie in the west, the Old Rhine in the north (between Leiden and Utrecht), the Gouwe in the east (between Gouda and the Old Rhine), the Hollandse IJssel in the south-east, and the New Meuse in the south (Erfgoedhuis Zuid-Holland)

In this report strategies are developed to cope with climate change in this area, using the past as a source of inspiration. Important elements of these strategies are the construction of additional water storage capacity and the restoration of an old shipping route between the Rotte (the old peat river that gave Rotterdam its name) and the Old Rhine.

The basis for the research was laid by two MSc theses at the Delft University of Technology: *Water as a carrier for future values; A design for the longterm transition for the Benthuizer Noordpolder, the Nether-*


**Figure 4**: The study area and its environs in 2022. Brown indicates greenhouses.[10]

*lands*, by Esmee Kuit, and *A climate proof buffer for South Holland; Bringing back history in the future's landscape*, by Coen Kramer.[11] These theses have subsequently been integrated and complemented, resulting in this report.

Research for this report has been funded by the province of South-Holland in het framework of the so-called heritage line (*erfgoedlijn*) tow barge canals. Key principles of the province's heritage policy are the importance of heritage for the environment and the contribution it can make to spatial quality, the identity of the landscape and the well-being of its inhabitants and visitors.[12] Since 2012, the province uses so-called heritage lines to implement its heritage policy. Heritage lines are geographical structures (the coast, the old dunes, etc.) that link monuments that tell a common historical story and form a line on the map. The heritage line tow barge canals is one of these lines.

In the next chapter the development of the study area since 900 CE and the current situation are described, focusing on water and water management. For this chapter much use has been made of the historical literature on this topic. The following chapter discusses the climate change challenges in the area and potential solutions for these challenges. This chapter is based largely on the MSc thesis by Coen Kramer. The final chapter details one potential solution and presents a first design for the Benthuizer Noordpolder area, including a restored connection between the Rotte and the Old Rhine. This chapter is based mostly on the MSc thesis by Esmee Kuit.

# 2. The development of the area

## The natural environment

The study area has undergone many changes since the last glacial period.[13] Eleven thousand years ago, the sea level was much lower than it is today and it was possible to walk from (what would later become) the Netherlands to (what would later become) England. Since then the sea level has risen significantly. When sea level rise slowed down, some 6,000 years ago, sand banks and dunes were formed in front of the coast and behind them reed swamps and car fens developed. In these waterlogged environments dead vegetation did not decompose completely and gradually peat soils built up. At some locations, such as the Zoetermeer area, the peat soils rose above the highwater level and raised bogs with peat moss (*Sphagnum*) and grass developed.

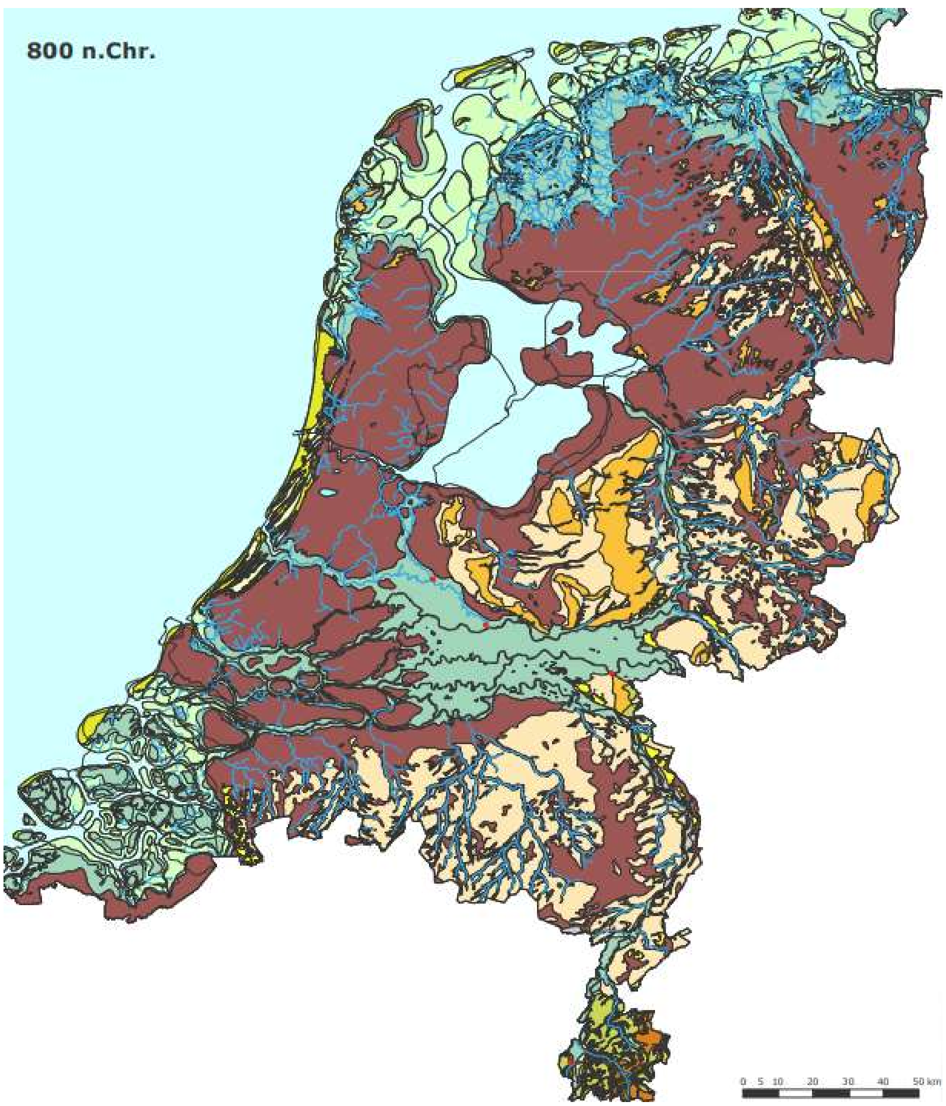


**Figure 5:** Paleogeographical map of the Netherlands in the year 800 CE. Brown is peat.[14]

Through these swamps and fens the Old Rhine and the Meuse found their way to the North Sea. Along their banks, they deposited silt and clay and natural river banks developed. Around the start of the current era, the influence of the sea grew in the south-western part of the study area. Tidal creeks developed and marine clays were deposited on top of the peat. In later centuries, however, peat gained the upper hand again. Figure 5 presents a reconstruction of the situation in the year 800 CE.

## Drainage

The first inhabitants in the region settled on the river banks of the Old Rhine, the Meuse and the smaller tidal creeks. The possibilities to live and work on the peat itself were limited. This changed when the peat was drained. In the south-eastern part of the study area, ditches were dug and small dams were constructed already in the iron age and the Roman period to control the water level better, but these structures have left few traces in the landscape.[15]

From the second half of the 9th Century onwards, peat was drained at a much larger scale. Starting from an existing waterway, ditches were dug perpendicular to that waterway to lower water levels and facilitate agriculture. This worked well initially, but a side effect was land subsidence. The peat shrank as water was removed and afterwards the peat decomposed gradually as oxygen entered the soil. Along the waterway dykes became necessary to prevent flooding. In addition, small dykes at the back and along the sides of the drained area were necessary to prevent water rushing in from undrained, still higher land.

The first mediaeval drainage works probably took place in the neighbourhood of Vlaardingen and Rotterdam in the 10th Century. The drainage works at Delft and Pijnakker date from before 1063 CE. The last drainage works, near Zegwaard and Benthuizen, took place around 1400 CE. The main purpose of these works was probably peat mining.[16]

## Peat mining

Peat mining posed as much a challenge for the study area as land subsidence. Already in the Mediaeval period peat was cut to serve as fuel, but from around 1530 onwards it was increasingly dredged (*slagturven*: see figure 6, next page). This resulted in large and deep peat lakes, such as the Noordplas near Benthuizen and the lakes on both sides of the Rotte river (figure 7, next page). Nearly all these lakes have been reclaimed in the 18th and the first half of the 19th Century. They can be recognised in the current landscape by their low elevation (figure 8, p. 9).

## Economic development and commercial conflicts

The large-scale drainage works led to a steady population growth. The employment possibilities in agriculture were not limitless and they decreased in time as a result of land subsidence, water problems and peat mining. But peat mining itself provided ample employment oppostunities. Bby the end of the 15th Century it had become the main occupation in many villages.[17] In addition, there were excellent possibilities for shipping and trade. In the 13e Century trading towns developed at strategic places on the waterways, such as Schiedam and Rotterdam (at dams in the Schie river and the Rotte river), Leiden (near the caste of the Count of Holland on the Old Rhine) and Gouda (at the location where the Gouwe river flowed into the Hollandse IJssel). In the 17th Century the waterways between these cities were turned into tow barge canals to promote public transport and trade.[18]


**Figure 6**: Peat mining by dredging circa 1742 (Jan Caspar Philips, Rijksmuseum Amsterdam). Peat is dredged using a "didle"[19] (*baggerbeugel*), spread on the land, and stamped down. When it is firm enough, it is cut into turves, which are then stacked to dry. In the background the final product is transported to the market. In a later stage the remaining strips of land would be cut.

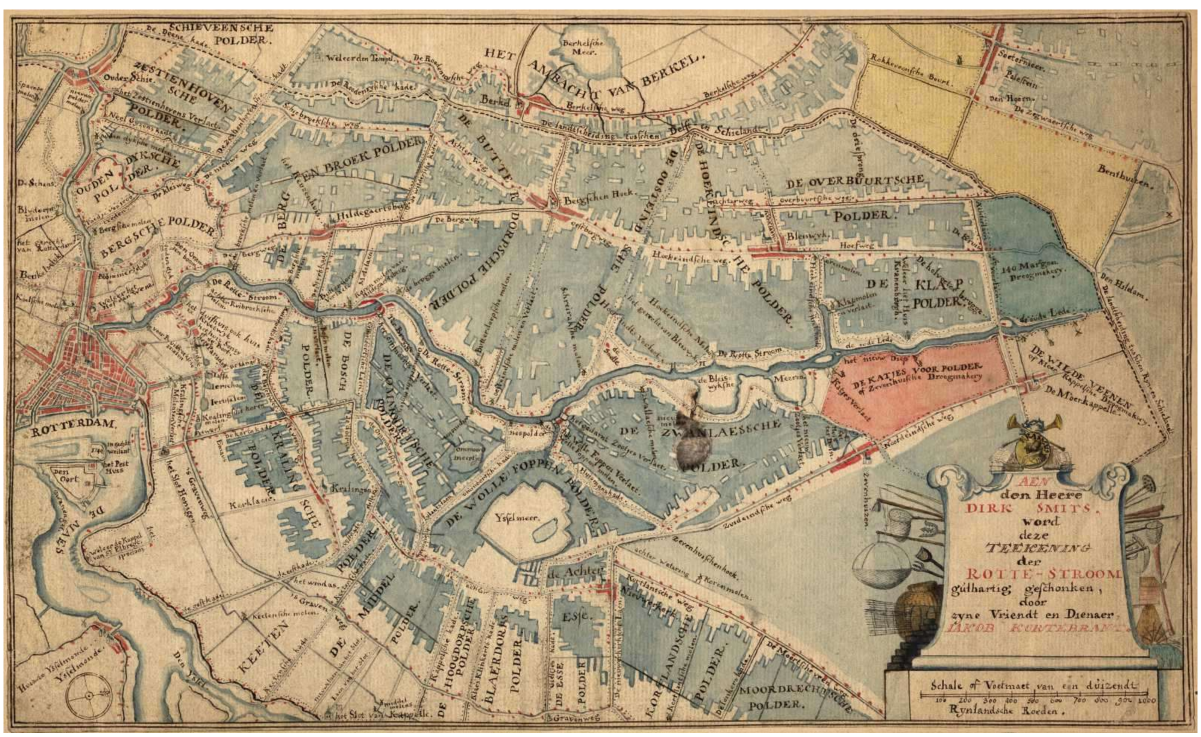


**Figure 7**: Map of the Rotte river circa 1750. The north is to the right. At the far right the Noordplas is partly visible and a little above the middle the Hildam is indicated.[20]

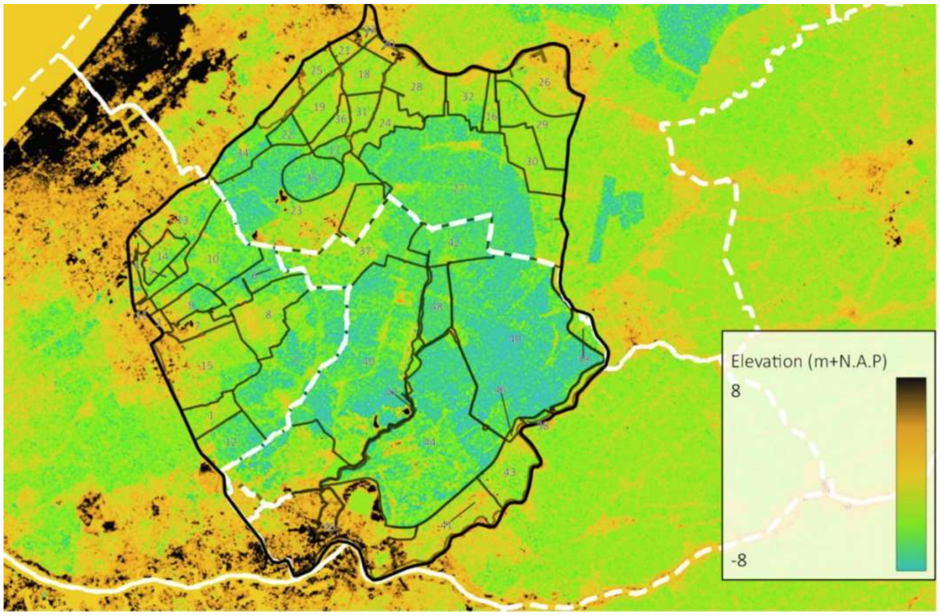


**Figure 8**: Elevation map of the study area, showing the individual polders and the boundaries between the three water board in the area (PDOK data, Kramer p. 82)

The cities did not always cooperate well and especially not when inland shipping was concerned. The usual shipping route from Rotterdam and Delft to Amsterdam was via Gouda. The locks in Gouda were, however, quite small, which caused congestion and delays. Shorter and quicker routes were the Schie and the Vliet via the Leidschendam (figure 9, next page) and the Rotte and the Hoogeveense canal via the Hildam. Gouda, however, wanted to keep the trade in its own city and opposed the construction and enlargement of locks in the Leidschendam and the Hildam. In 1492 and 1493 Gouda even sent a large contingent of carpenters and smiths, armed with axes, saws, hammers and battering rams, to the locks to destroy them. This was repeated in 1590, when Gouda destroyed the winch at Hildam, which was used to pull small boats over the dam.[21]

## Water management

Initially, water management in Holland was a local issue. The land owners and users were responsible for the maintenance of the ditches, canals and dykes. The local jurisdictions (the predecessors of the municipalities) supervised whether they met their obligations. In time, the water management challenges became too big to be handled locally and regional water boards were established. In the study area there were three: Rijnland, Delfland and Schieland.

Water board Rijnland was established in the 13th Century to supervise the construction and maintenance of new canals between the Old Rhine and Lake Haarlem (*Haarlemmermeer*) and new sluices between Lake Haarlem and the IJ water, which had an open connection with the North Sea. These canals and sluices had become necessary as a result of sedimentation of the mouth of the Old Rhine.[22] In the Delfland region, the mouth of the Schie was dammed to protect the area behind the dam against flooding. To secure the drainage of the area that formerly drained via the Schie, the Poldervaart was dug, a straight canal from

**Figure 9**: The Leidschendam circa 1678 (Coenraet Decker, Rijksmuseum Amsterdam). Because of opposition by especially Gouda, it was only in 1648 that a simple lock was constructed in the dam. In 1886-1887 the lock was replaced by the current much larger lock.

the Schie to the Meuse with five sluices at the end.[23] In addition, dykes along the Meuse had been built, which did not only protect the local jurisdiction in which they were located, but also the neighbouring jurisdictions. Hence, these dykes required regional supervision too.

Large parts of the Schieland area drained via the Rotte river. They had a common interest in the dam in the Rotte, constructed circa 1270, in the sluices in the dam, and in the dykes that protected against river flooding.[24] Like the water boards Rijnland and Delfland, the water board Schieland initially had a supervisory task only; only in later centuries did the water boards start to operate and maintain infrastructure themselves. In 2005, water board Schieland merged with the neighbouring water board Krimpenerwaard and is now called in full water board Schieland and the Krimpenerwaard.

The tow barge canals and the other waters that form the boundaries of the study area are mostly older than the water boards. The Old Rhine, Hollandse IJssel and New Meuse  are heavily modified natural rivers. The Gouwe was originally a peat stream that discharged its water onto the Hollandse Ijssel. Before 1244 it was connected upstream with the Old Rhine.[25] The Schie was originally a tidal creek and peat stream, at least the downstream part between the village of Overschie and Schiedam.[26] The part between Delft and Overschie, the Delftse Schie, was dug in different stages and existed already, partly or wholly, in the middle of the 11$^{th}$ Century.[27] The age of the Vliet is hard to determine because of the scarcity of written sources. The part between Leiden and Rijswijk, the Leidsche Vliet, follows largely the route of the Roman

Corbulo canal.[28] The Delftsche Vliet connects Delft with the Leidsche Viet and was dug at the earliest in the last quarter of the 12th Century.[29]

Between the three water boards there were so-called land boundaries (*landscheidingen*).[30] These had developed gradually as the small dykes at the tail end of adjacent drainage project became connected. It was not allowed to cut through the land boundaries or mine peat close to them. These rules were especially important for Delfland and Schieland since water levels in Rijnland were often higher than in these two water boards. Nonetheless, the land boundaries were weakened by peat meaning on the Delfland and Schieland side too. In many cases the land boundaries were preserved only because the resulting peat lakes were reclaimed.

From the 15th Century onwards, polders were established in the area. Individual land owners and groups of land owners separated their land from the “bosom water” – the large drainage canals and the connected lakes – by means of small dams and dykes, and erected a windmill to pump out water and lower the water level. This resulted in even more land subsidence. In time, the windmills were replaced by steam pumps and later diesel and electric pumps. In the process many polders were merged as it was often cheaper to install one large pump than two or more smaller ones. The boards governing the polders were merged as well, and in 1973 all polder boards in the Schieland area merged with the water board. In 1976 Delfland followed suit and Rijnland, after some intermediate steps, followed in 2004.

From the 18th Century onwards, artificial drainage was introduced for the bosom waters too. Initially, this was only to support natural drainage when river water levels were too high for the bosom waters to discharge their water by means of gravity. Schieland was the first: already in 1741 Rotterdam erected a wind mill and in 1772 the water board itself erected eight large wind mills to pump out water from the Rotte onto the New Meuse. Rijnland got its first pumping station for its bosom waters in the 1850s to compensate for the reclamation of Lake Haarlem. The reclamation of this lake would significantly decrease the surface area of its bosom water, and without compensation the water level of the remaining bosom waters would rise too much when natural discharge was temporarily not possible. Delfland got its first bosom pumping station in 1864.

The water boards can not only pump out water, they can also let in water from the Hollandse IJssel and, via a pipeline under the Nieuwe Waterweg (the shipping route between Rotterdam and the sea), from the Brielse Lake (*Brielse Meer*). This especially important in summer (see the next chapter).

Throughout the ages, water governance in the area has undergone many changes.[31] However, they are still responsible for controlling water levels in their area, preventing floods and water logging and supplying fresh surface water.[32]

## The present

The study area is presently highly urbanised. Zoetermeer grew from a village with 1010 inhabitants in the middle of the 19th Century to a city with 127,031 inhabitants presently, and Delft grew in the same period from a small city with 17,000 inhabitants to a city with 106,094 inhabitants.[33] Also the other villages and cities in the area have grown significantly. In addition, many greenhouses have been built and much new transportation infrastructure has been constructed, such as the railway lines in the 19th Century, motorways in the 20th Century and a highspeed railway line in 2009. In the remaining open areas there

**Figure 9**: A polder mill (“In the month of July”, Paul Gabriël circa 1889, Rijksmuseum Amsterdam)

are some smaller nature reserves and several recreation areas, such as the Bentwoud (Bent forest) near Benthuizen. The rest of the open area is agricultural: meadows and pasture on the peat soils and fields in some of the reclaimed lakes (figure 4).

Despite a high degree of fragmentation, the area still contains many valuable elements, such as historic city centres. The tow barge canals and tow paths connect these city centres with each other. They provide visually attractive boating and bicycle routes. As such, they are part of larger networks of boating and bicycle routes. They moreover connect the polders in the area with the rivers and the sea. They were and are essential for discharging excess water; the Delftse Schie and the Vliet have even been dug specifically for this purpose. They are inextricably linked with the Mediaeval drainage of the area and with the development of the cities.

The tow barge canals can also provide social connections. They offer the inhabitants of South-Holland recreational possibilities close to home at low or no costs. In addition, they can be used to tell the story how earlier generations interacted with each other and with their environment and how this shaped South-Holland, and to start a dialogue on the future.

# 3. Climate change

Climate change will have a large impact on the study area. In this chapter, strategies are developed to limit the impact and simultaneously add value for recreation, nature and landscape.

## Current water management

Currently, there are 49 polders in the study area. The water levels in the polders differ and are especially low in the reclaimed peat lakes, up to -7,00 m Amsterdam Ordnance Data (*NAP*) in the Prins Alexander en Eendragts polder (nr. 44 in figure 11).[34] Excess water is pumped out onto the bosom waters (dark blue in figure 11). The level of the bosom waters differ too. In Rijnland it is -0.61 m NAP in summer and -0.64 m NAP in winter, in Delfland it is -0.43 m NAP all year round and the water level of the Rotte in Schieland is -1.02 m NAP, with a broad margin between -0.90 m and -1.2 m NAP. The ring canal of the Zuidplaspolder, east of the Rotte, is a separate bosom with a water level of -2.15 m NAP. From the bosom big pumping stations pump out the water onto the Hollandse IJssel, New Meuse and the North Sea. Two polders (nr. 41 and 43) and part of the town of Capelle aan de IJssel discharge directly onto the Hollandse IJssel.

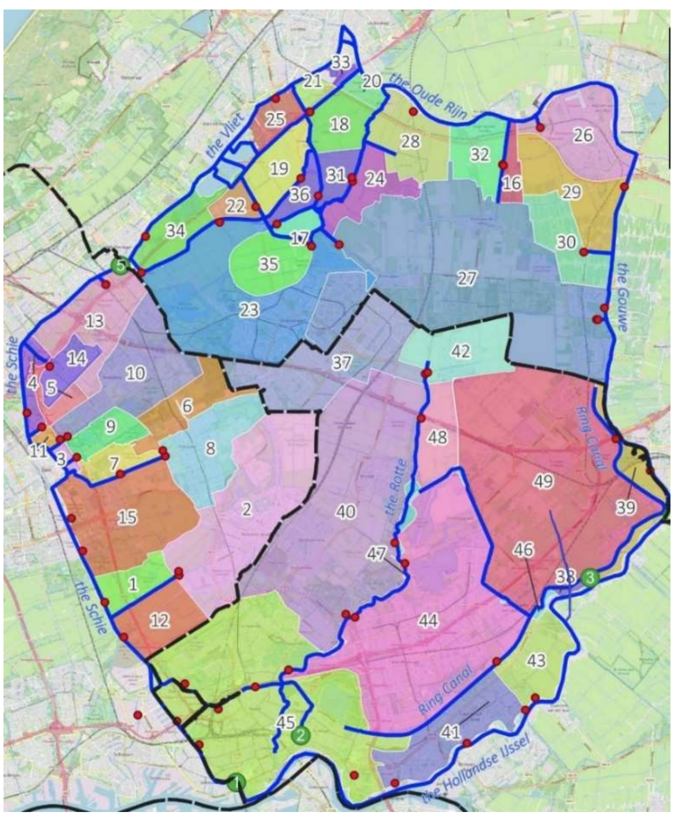


**Figure 11**: Polders, bosom waters (dark blue), polder pumping stations (red) and bosom pumping stations (green) in the study area (Kramer)

Via the bosom water can be let in. Rijnland can let in water from the Hollandse IJssel at Gouda and Schieland at Moordrecht. Delfland can let in water from the Brielse Lake, outside of the study area, via a pipeline under Nieuwe Waterweg and pumping station Winsemius. In addition, the water boards can exchange water. Delfland can pump water up at Leidschendam from the Rijnland part of the Vliet (green 5 in figure 11) and Schieland can let in water from Delfland at the Berg sluice in Rotterdam.[35] In addition, water can be imported during serious droughts from further upstream via the Leidse Rijn and the Old Rhine, the Amsterdam-Rijn Canal and the Lopikerwaard region. This is the so-called Climate-proof Water Supply Arrangement (in Dutch KWA; figure 12).

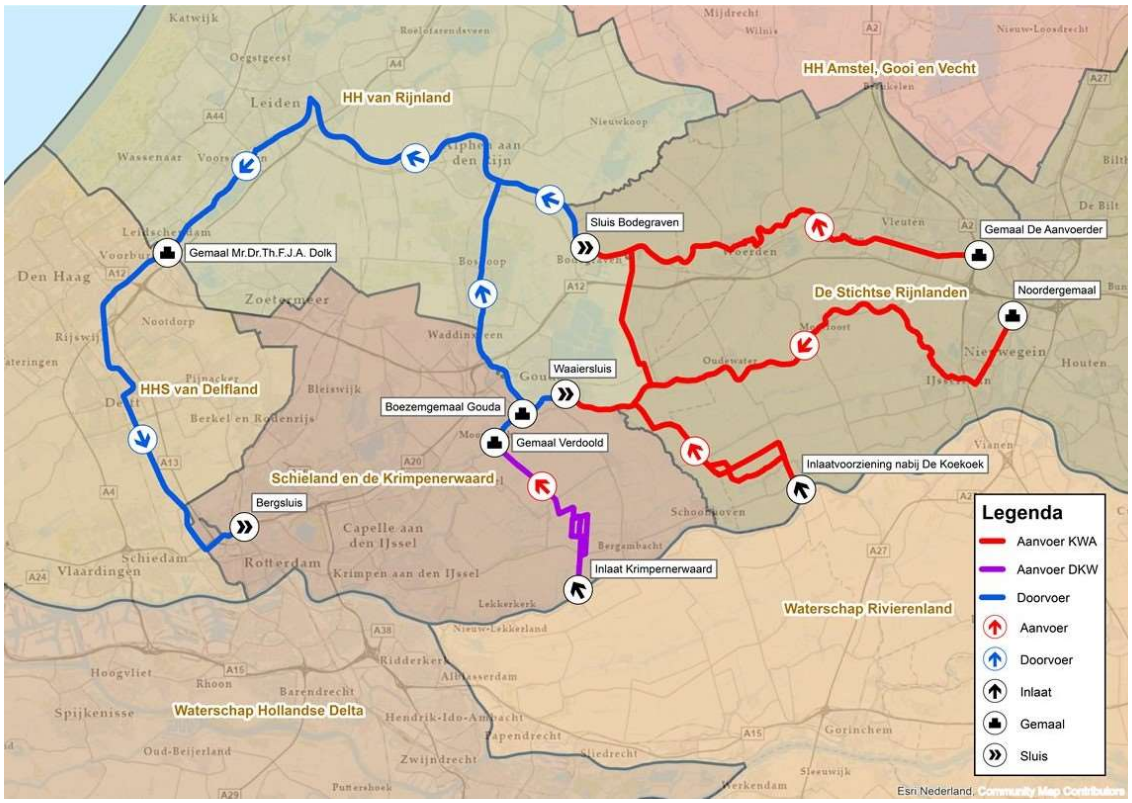


**Figure 12**: The Climate-proof Water Supply Arrangement (KWA, red), the Throughflow Krimpenerwaard (DKW, purple) and the route for further distribution in the Rijnland, Delfland and Schieland area (blue)[36]

Water often has to be let in in summer, when there is little or no rainfall and evaporation is high. In addition, water is needed to flush the polders. Due to their low elevation, often below mean sea level, brackish groundwater seeps up and this has to be flushed out. Yet, river discharge in summer is often low and saline seawater can travel far in land. This can result in too high chloride concentrations at Moordrecht and in exceptional cases even at Gouda. For this reason, the Winsemius pumping station was built in the years 1986-1988 and the KWA was developed since 2003.

The pumping stations of the different polders and of the bosom waters are all owned and operated by the water boards. The water boards are also responsible for the dykes and the other flood defences. In addition, they are responsible for the chemical and ecological quality of the surface waters in their area and for urban wastewater treatment.

The water boards have limited powers to control emissions from agriculture or building materials.[37] They also have limited powers in spatial planning, even though spatial planning is very important for water management. When new residential or commercial areas are developed, the total area of hard surfaces increases. As a result, less rainwater can infiltrate into the ground more rainwater ends up in the ditches and canal. This increases flooding. To complicate matters, flooding standards for residential and commercial areas are much higher than for undeveloped land. The costs a water board has to make to meet the higher standards, for instance the costs of additional pumping capacity, have to be covered by the developers. In addition, there is nowadays much attention for "blue-green" solutions, such as increasing the space for greenery and replacing impermeable pavement by permeable pavement.[38]

Water boards are in many cases not responsible for shipping and boating. For the so-called State waters, such as the New Meuse and the Hollandse IJssel, this is the State (*Rijkswaterstaat*). For the provincial waterways, such as the Schie, Vliet, Old Rhine and the Gouwe, this is the province (*Gedeputeerde Staten*, the executive council).[39] For the so-called regional waterways, the water board or the municipality is responsible (figure 13). When for instance bridges over provincial or regional waterways are replaced, the width and height for boats may not be reduced.[40] In addition to the waterways officially designated as such, there are many other waters that are used for boating. For these waters the water manager, usually the water board, is responsible.[41]

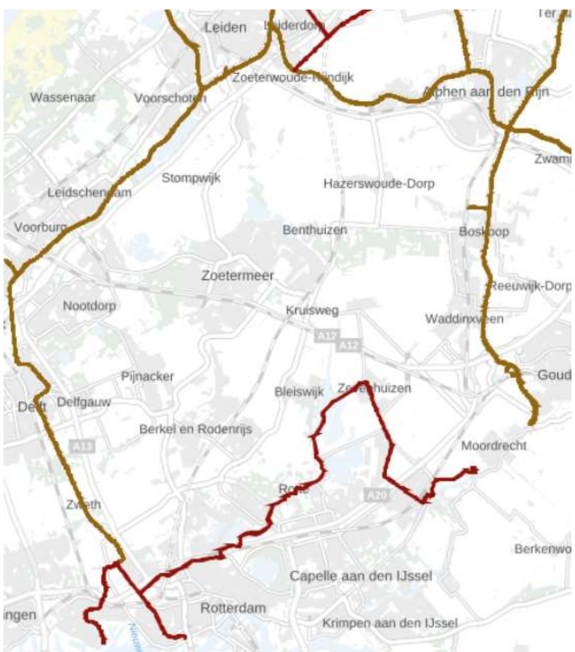


**Figure 13**: Provincial (green) and regional waterways (red) in the study area[42]

Sewers and drinking water supply are the responsibility of the municipalities and the drinking water companies respectively.

## Challenges

There are a number of water management challenges in the area. First, the flood defences along the main rivers and the coast will have to be strengthened when the sea level rises. This can be combined with closing off the rivers with dams. The river dykes then have to strengthened less, but huge “river pumping stations” will have to constructed to pump out the river water to the sea. A lot of research is already done on these options.[43] In this report it is assumed that this challenge will be handled well.

Secondly, pluvial flooding may increase as a result of climate change. Nobody knows exactly how quickly and how much the climate will change. To provide some basis for water management, the *KNMI*, the Royal Netherlands Meteorological Institute, has developed four climate scenarios for the Netherlands, which are based on the global climate change scenarios of the Intergovernmental Panel on Climate Change (IPCC).[44] In the study area precipitation in a wet year may increase from 1015 mm in 2001 to 1430 mm or even 1521 mm in 2100.[45] In addition, 342.700 new houses have been planned in the province of South-Holland, including many in the study area (figure 14).[9] This will significantly increase the total area of hard surfaces and require higher flooding standards.

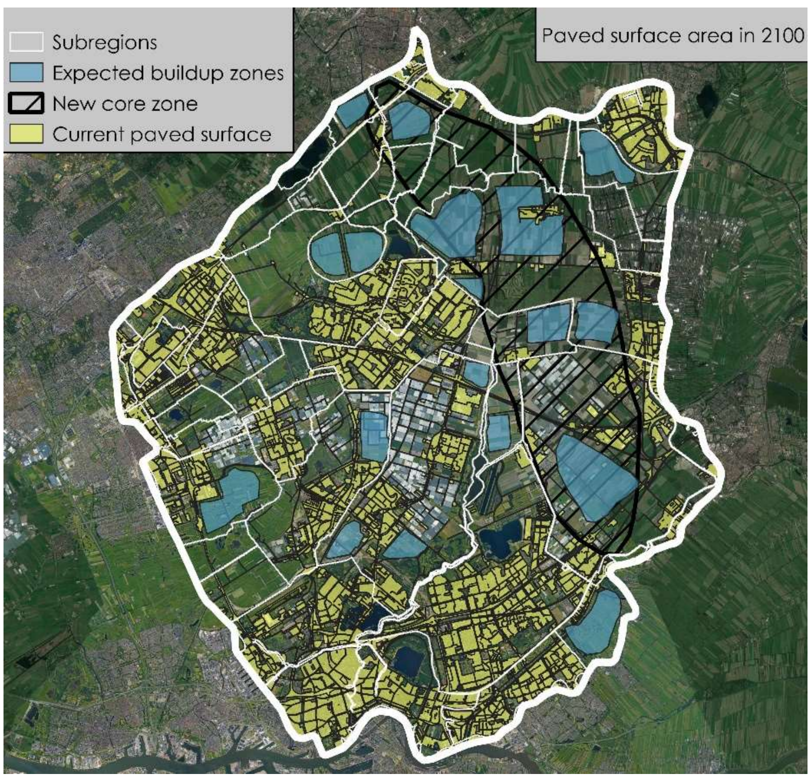


**Figure 14**: A scenario for the increase in hard surfaces in 2100 (Kramer, p. 42)

Thirdly, drought problems can increase. Precipitation in a dry year may decrease from 679 mm in 2018 to 638 or 622 mm in 2100, depending on the climate scenario.[40] Moreover, the periods without any rain at all will become longer. Water shortages will increase even further because evaporation will increase as a result of higher temperatures, while river discharges will decrease. The lowest discharge of the Rhine may decrease by as much as 50% as a result of increasing drought in Germany and France and the shrinkage of the glaciers in the Alps.[46] Together with sea level rise, this will increase salt water intrusion in the area.[47]

The fourth challenge is water quality. As elsewhere in the Netherlands, the objectives of the European Union's Water Framework Directive have not been met. This may result in heavy European fines.[48] This report does not focus on water quality issues, but solutions for flood and drought problems may contribute to solving water quality issues and vice versa.[49]

## Strategies

The most obvious strategy for solving pluvial flooding problems seems to be to increase the capacity of the pumping stations. The capacity of a polder pumping station is now in the order of 0.5 mm/ hour; rainfall above this amount has to be stored temporarily, e.g. in the soil or the surface waters. If an increase in rainfall is to be solved exclusively by increasing pumping capacity, this has to increase disproportionally much. Suppose for instance that a polder can cope with 100 mm of rain in a day: 15 mm is pumped out and 85 mm is stored temporarily. If in the future the polder should be able to cope with 15 percent more precipitation, so with 115 mm/day, and storage capacity remains 85 mm/day, pumping capacity should go up 30 mm/ day. This is an increase of 100 percent.

Apart from the costs of such an increase, many waters in the polders are too small to transport that much water. In addition, the capacity of the bosom pumping stations would have to be increased disproportionally as well, and some bosom waters are too small as well (e.g. the Binnenrotte in Rotterdam). Increasing pumping capacity is therefore not a complete solution for pluvial flooding problems. Extra temporary water storage will be required as well.

Drought problems could in theory be reduced by letting in more freshwater from the New Meuse and the Hollandse IJssel, but these rivers will become too saline more often. Water could then be transported from further upstream, for instance by increasing the capacity of the KWA. Whether this is technically possible and at what costs is still unclear: river discharges are expected to decrease significantly in summer and the demand for fresh river water elsewhere in the country will increase too. Another option is to reduce salt water intrusion by building a lock in the Nieuwe Waterweg. Yet, when operating the lock large quantities of saline sea water will continue to enter the area. Measures to reduce this, such as a bubble screen behind the lock, require a lot of energy or space.[50]

It seems that also for limiting drought problems, extra temporary water storage is a promising strategy. Extra storage against drought can be combined with extra storage against pluvial flooding, but there is some tension between these two purposes. For limiting drought problems, the storage should be kept full as long as possible so that water is available when it is most needed. For limiting flooding problems, however, the storage should be kept empty as much as possible so that the full capacity is available when a heavy rainstorm occurs.

For the sake of completeness, another solution for drought problems should be mentioned too: accepting higher chloride concentrations. The financial costs of this solution are low, but the social and economic costs are high. It does not only have a large impact on agriculture, but also on nature areas that depend on freshwater. On the positive side, it offers opportunities for new brackish nature.

## Water storage

A key issue concerning extra temporary storage is how much is needed. To calculate this, a water balance model of the different polders in the study area has been made (see the Box). The water balance of an area provides an overview of the main water flows into and out of that area. If more water goes in than out, the available storage gets full and flooding may occur. If, however, more water goes out than in, the area dries out. The vegetation then starts to grow less or even dies, peat soils dry out, land subsidence increases, local dykes made out of peat may become unstable, and wooden piles, on which many older Dutch houses are built, start to rot.

**The water balance model**

For the water balance model of the area the most important water flows into and out of the different polders have been inventoried. The most important flows into a polder are precipitation (presently on average 858 mm/y), groundwater seepage (between 0 and 375 mm/y, depending on the elevation and soil type) and water inlet from the bosom. The most important water flows out of a polder are evaporation, infiltration in the soil (between 0 and 260 mm/y) and discharge onto the bosom (ranging between 250 mm/y and more than 1,000 mm/y). In addition, there is some exchange of water between the polders via for instance culverts and the subsoil.

Complicating factors are drinking water, which is imported from outside the area, and the sewers, which export wastewater to a sewage treatment plant (stp). In case of a separated sewer system, with separate wastewater sewers and rain drains, only wastewater is exported to the stp and this outflow more-or-less equals the import of drinking water. In case of combined sewers, a mixture of wastewater and rainwater is transported to the stp.

Not all data for closing the water balance are available. The inlet of water is not measured and evaporation is estimated. Evaporation from open water can be approximated well using for instance temperature or solar radiation data, but evaporation from the land is very complex. Evaporation from the land consists of evaporation from wet surfaces, such as roofs and roads (interception), evaporation from wet soils (soil water evaporation), and water use by the vegetation (transpiration). How much this is depends on factors such as the percentage of hard surfaces, the type of vegetation (e.g. grass or trees), the season, how often and how much it rains, temperature, solar radiation and wind.

When data are lacking, assumptions have to be made. For open water evaporation the so-called reference evaporation is used. This is the evaporation from grassland when sufficient water is available. For evaporation from land, the reference evaporation is modelled as a fixed percentage of the reference evaporation. This percentage is chosen in such a way that the calculated amounts of water that are pumped out match as much as possible the measured amounts.

More details on the model can be found in the MSc thesis of Coen Kramer, mentioned in the introduction.

To estimate the effects of climate change in 2100, the current precipitation and (reference) evaporation data in the model have been replaced by the expected precipitation and evaporation in 2100 according to the climate scenarios of the KNMI. Moreover, the expected sea level rise and soil subsidence, important for the expected amount of groundwater seepage, have been factored in.[51] In addition, assumptions have been made concerning the increase in hard surfaces. A further assumption is that 30% of the new hard surfaces will be permeable.

The results of this exercise are that both water shortage and pluvial flooding will become more common. To prevent an increase in pluvial flooding problems, 7.5 mln $m^3$ of extra temporary water storage is needed, and to prevent an increase in drought problems, 34 mln $m^3$ is needed. Since extra water storage against pluvial flooding can be combined with extra water storage against drought, the total extra temporary storage needed is 34 mln $m^3$. This is based on the assumption that in 2100 weather forecasts have improved to such an extent that heavy rainstorm can be predicted well 48 hours in advance. If at that moment the temporary water storage is full, the water managers still have 48 hours to pump out water and create more storage.

## One large Bent lake

To create 34 mln $m^3$ of extra temporary water storage, there are at least four options:

- One central storage for the whole study area
- Large-scale storage for the individual water boards
- Additional storage in the individual polders
- A combination of the first and the third or the second and the third option

A good location for central storage is east of Zoetermeer in the polders Noordplas (Rijnland) and De Wilde Veenen (Schieland; see figure 15). The Noordplas was a peat lake that had developed from the 16th Century onwards as a result of peat mining and was reclaimed in the years 1759-1766.[52] Polder De Wilde Veenen also was a peat lake, but it was already reclaimed in the middle of the 17th Century. In this area the Bentwoud (Bent forest) is located, a newly created nature and recreation area of 800 ha, completed in 2016. There are few buildings in the area.

Because of their low elevation, the two polders are ideal for storing water. Assuming 1.7 metre difference between the lowest and the highest water level, the lake should get a surface area of 20.1 $km^2$. A good name for the new lake would be Bentmeer (Bent lake), as it is close to the village of Benthuizen (Bent houses).

The Bent lake offers good possibilities for water recreation. In addition, it offers possibilities to restore the Hoogeveense canal, which connected the Rotte with the Old Rhine. The southern half of this canal has disappeared into the Noorderplas and has not been reconstructed when the Noordplas was reclaimed. Via the Old Rhine, the Vliet and the Schie, water can be exchanged with other parts of Rijnland and with Delfland. The route to and from Schieland is southwards, directly to the Rotte.

The additional works that will be needed depend on the future water level of the Bent lake. If the water level will be between 30 and 200 cm below the water level of the Rotte (between -1.5 NAP and -4.20 NAP), it will be possible to quickly let in water from the Rotte bosom and the Rijnland bosom in case of a threat of flooding. This assumes that the transport capacity of the Rotte and the Hoogeveense canal is large enough. The biggest constraint, however, is the capacity of the polder pumping stations (see supra).

During droughts water from the Bent lake will have to be pumped up some two meters. This requires two new pumping stations: one on the north side of the Bent lake to supply Rijnland and Delfland with water and one on the south side for Schieland. In addition, two new locks will be necessary, assuming the new part of the Hoogeveense canal is constructed at bosom level. If it is constructed at the lower polder level,

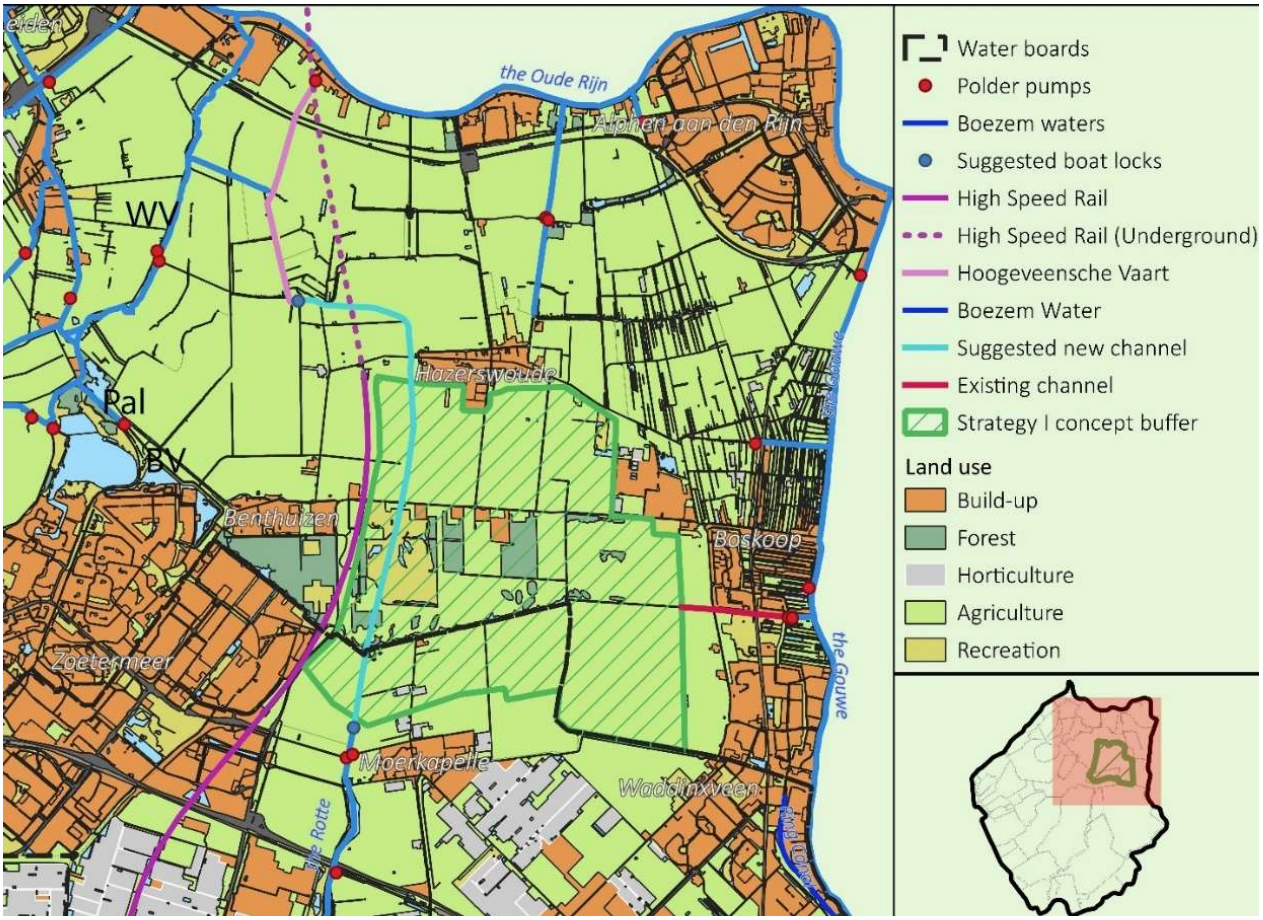


**Figure 15**: Option 1, central storage in the Bent lake (Pal: pumping station Palenstein, BV: Benthuizer canal, WV: Weipoortse Vliet) (Kramer, p. 54)

below the water level in the Bent lake, the pumping station at the north side will have to become much bigger to quickly pump up excess water from Rijnland and Delfland in case of a threat of flooding. In addition, a third pumping station will be needed to pump up water during droughts from the new part of the Hoogeveense canal to the bosom level of Rijnland, as well as possibly a third lock.

Since in summer the water level in large parts of the Bent lake may become too low for boating, a navigation channel may have to be dredged. In addition, adjustments will be necessary to the bridge of the A12 motorway and the railway bridge over the Rotte near Moerkapelle. Finally, new dykes may be necessary around (parts of) the Bent lake and along the new part of the Hoogeveense canal if constructed above the polder level.

More details on the connection between the Bent lake and the Old Rhine and the challenges of facilitating boating can be found in the next chapter.

## Large-scale water storage per water board

A Bent lake of more than 20 km$^2$ is of course very large. An alternative is to construct storage lakes for the individual water boards (see figure 16). In this alternative the Bent lake is 6.8 km$^2$ and it is meant exclusively for Rijnland. This also means no pumping station will be needed to pump up water into the Rotte during droughts. Assuming the water level of the lake will be below the level of the Rotte, it will still be possible to let in water from the Rotte if there is threat of flooding in Schieland and there is still unused storage capacity in the Bent lake. The same applies if there is threat of flooding in Delfland, but the route for the water in that case is much longer (Schie – Vliet – Old Rhine – Hoogeveense canal). As in the first option, the additional works that are required depend on the future water level of the connection with the Old Rhine. The pumping stations that will have to be built can be smaller.


**Figure 16**: Option 2, large-scale storage per water board (Kramer, p. 56)

A good location for extra storage in Schieland is the Eendragtspolder, where the capacity of the existing storage lake can be increased by 8 mln $m^3$. The Eendragtspolder is located between the Rotte and the Ring canal and it is therefore well connected with the rest of the area. Eight mln $m^3$ is, however, not enough, so extra storage will have to be created in the Zuidplaspolder as well, the only part of Schieland within the study area that has not yet been built up. Here a lake of 6.9 $km^2$ would be needed, assuming 1.7 m difference between the highest and the lowest water level. In Schieland too new pumping stations would be needed.

Good locations for extra storage in Delfland are the polders Berkel and Schieveen. In the polder Berkel water storage has already been created, but the capacity can be increased by 1.2 mln. $m^3$ to 2.8 mln. $m^3$. As to Schieveen, there are plans to change this polder into a nature area. This can be combined with temporary water storage, but nature in a meadow birds area, which it currently is, is of course very different from nature in an area that is regularly or permanently flooded. With a surface area of 3.26 $km^2$ and assuming, again, a maximum water level difference of 1.7 m, the storage capacity in the polder Schieveen would become 5.54 mln. $m^3$.

The total water storage capacity is the same as in the first option. The most important limitation of this option is also the same as that of the first option: the capacity of the existing polder pumping stations. This will have to increase disproportionally if no extra storage within the polders is created.

## The decentralised option

The third option is extra water storage in the individual polders. In this option, the capacity of the existing polder pumping stations is much less of an issue because excess water does not have to be pumped out first before it can be stored. Bottlenecks in the bosom are not an issue either, but bottlenecks within the polders, such as too narrow culverts, are. These bottlenecks also have to be addressed in the first two options. Important disadvantages of the decentralised option are, firstly, that not in every polder there is space of extra water storage. Secondly, in case of local rainstorms, there may be pluvial flooding in one polder while there is still enough storage capacity in a neighbouring polder. Water then has to be transported from the first polder into the second polder. And thirdly, there will be few opportunities for more water recreation or none at all.

## Combination option

The combination option consist of 7.5 mln $m^3$ of extra storage in the individual polders and a central Bent lake of 26.5 mln $m^3$. The decentralised storage is meant primarily to reduce pluvial flooding. If in a polder there is no space for extra storage, this can also be created in a neighbouring polder, provided they are connected with a culvert or in another way. The decentralised storage can also be used to supply water during droughts. If the decentralised storage is full and a heavy rainstorm is predicted, water should be pumped out in advance to create the necessary storage.

The Bent lake is used in this option exclusively to supply water in drought periods. When a drought occurs, the water in the decentralised storages should be used first to restore the full capacity for reducing flooding, and after this the water in the Bent lake can be used. The Bent lake can be smaller than in the first strategy, 15.6 $km^2$, but this still offers good opportunities for water recreation. In addition, the water levels can be higher because there is no need to let in water quickly in case of a threat of flooding. If the average water level becomes the same as the summer level of the Rijnland bosom (-0.61 m NAP), the water level in the lake will range between -1.56 m NAP and +0.24 m NAP (assuming 1.7 m variation). This is 1.74 m higher than in the first two options. This results in a larger navigation depth, less warming up in summer and consequently a better water quality and less blue-green algae. It would also be possible to increase the maximum variation in water levels to for instance 2 m. This would further reduce the required surface area to 13.3 $km^2$ and the Bentwoud, which in the first option would have to go, might be saved.

A variant of the combination strategy is to combine option 2 and 3: 7.5 mln $m^3$ of decentralised storage in the polders to manage flood and drought problems and a total of 26.5 mln $m^3$ large-scale storage in the different water boards, exclusively for managing droughts. As in the second option, water could be exchanged between the water boards if for example the drought problems are bigger in one of the water board than in the other two.

## Discussion

All four options are based on a large need for extra water storage. The extra storage need is especially large to limit drought problems. It was assumed that water shortages in summer are not allowed to increase and that no extra water from outside the study area can be imported. If we relax these assumptions, for instance because a solution is found for salt water intrusion via the Nieuwe Waterweg, less water storage may suffice. The uncertainties are, however, large. If it appears in for instance 2050 that large-scale temporary water storage in this part of the country is needed, space for this has to be reserved quite soon.

The social costs of extra water storage and of spatial reservations are high, but the costs of other ways to adapt to climate change are high too.[53] Op top of that, the options presented here also have important benefits for recreation, nature and landscape, as well as the less tangible benefits of heritage.

In developing the four options, use has been made of historic elements, such as the tow barge canals as means to transport water and peat lakes as means to store water. The construction of peat swamps has been considered too but not chosen. Peat swamps can stop or even reverse the process of land subsidence, especially when raised bogs develop. As a bonus Carbon would be sequestered, resulting in less $CO_2$ in the atmosphere.[54] Peat swamps are, however, no solution for built-up areas. Moreover, water storage capacity is much smaller than in lakes with a variable water level, and it is dubious whether under the present circumstances (oligotrophic) raised bogs can develop.[55] Yet also without peat swamps the four options emphasise the strong historical link between water and South-Holland.

# 4. A new Hoogeveense canal and spatial design

In the preceding chapters the Hoogeveense canal has been mentioned several times. The Hoogeveense canal was dug in the late $14^{th}$ Century and became part of an alternative shipping route from Rotterdam to Amsterdam via the Rotte river that avoided Gouda.[56] The southern part of the Hoogeveense canal disappeared in the Noordplas and was not reconstructed when this peat lake was reclaimed. The northern part onto the Old Rhine still exists.

A restored Hoogeveense canal could connect the new Bent lake with the Old Rhine. By connecting the Bent lake with the Rotte as well, the shipping route between the Rotte and the Old Rhine would be restored, although this time more for boating than commercial shipping. There is, however, no a priori reason to reconstruct the Hoogeveense canal at the exact location where it used to be. On top of that, there are alternative ways to connect the Bent lake with the Old Rhine.

In this chapter the water management aspects of the Hoogeveense canal and its alternatives will be discussed first. This discussion is based on the combination option presented in the previous chapter: a Bent lake with a capacity of 26.5 mln $m^3$ storage capacity for drought periods and a surface area of 15.6 $km^2$, and on top of this local water storage in the different polders. Next, the spatial design of the area will be discussed.

## Water management

The Hoogeveense canal is meant to transport water between the Bent lake and the Old Rhine and as part of a "new" boating route. An obvious alternative if only the transport of water were an objective would be to use existing waterways. The Bent lake could be connected east of Benthuizen with the ring canal of the Noordplas polder via an underpass under the highspeed railway line. This ring canal is connected with the Benthuizer canal. At the end of that canal the pumping station Palenstein is located, which can discharge the water onto the Elleboogse Wetering. The Elleboogse Wetering has an open connection with the Old Rhine via the Noord Aa and the Weipoortse Vliet (figure 17, left). From there the water can be transported further to other parts of Rijnland and, via the Vliet and the Schie, to Delfland.

The differences in water level that have to be bridged in this option are limited: the Bent lake has a water level between -1.56 m NAP and +0.24 m NAP, the water level of the Ring canal and the Benthuizer canal is -1.89 m NAP, and the water level of the Elleboogse Wetering and the Weipoortse Vliet is the same as the water level of Rijnland's bosom, -0.61 m NAP in summer and -0.64 m NAP in winter. A new pumping station will be needed to pump water from the Ring canal into the Bent lake, as well as three new locks.

The biggest limitation of this alternative are the limited opportunities for boating. Water board Rijnland has designated the Weipoortse Vliet as "vulnerable water". This means that motor boats are only allowed with a permit from Rijnland and these will be given in exceptional cases only. Sailing boats and other taller boats will face the limited height of the underpass under the highspeed railway line. A draw bridge or a tunnel for the railway line are either not feasible or extremely expensive.

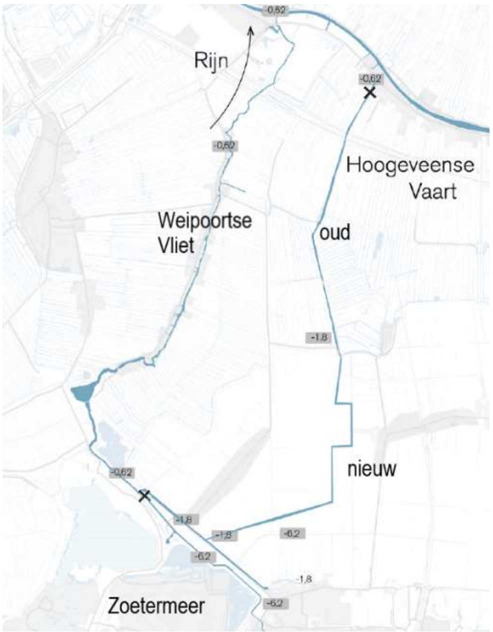


**Figure 17**: Connections between the Bent lake and the Old Rhine via the Weipoortse Vliet (left) and a restored Hoogeveense canal (right; Kuit, p. 87). “Oud” refers to the still existing part of the Hoogeveense canal and “new” to the part that is to be restored. Figure 15 shows the third option: a direct connection between the Bent lake and the remaining part of the Hoogeveense canal.

Two other connections that have been considered include the still existing part of the Hoogeveense canal. In the first case the Bent lake is connected on the north side with the existing Hoogeveense canal (figure 15), while in the second case a new part of the Hogeveense canal is dug between the Benthuizer canal and the existing Hoogeveense canal (figure 17, right). In both cases larger differences in water level have to be bridged. The water level of the existing Hoogeveense canal is -2.47 m NAP in summer and -2.57 m NAP in winter. The water level in polder de Noordplas that has to be crossed is up to -6.50 m NAP. This means that extra pumping stations will be needed. An alternative for the new part of the Hoogeveense canal is to construct this at the level of the Benthuizer canal or the existing Hoogeveense canal (see the next section).

The route via the new Hoogeveense canal passes under the highspeed railway line, just like the Weipoortse Vliet route, and has the same height limitations. The “north option” does not have this limitation because the highspeed railway line enters into a tunnel. Obviously, the height of the roof of the tunnel limits the depth of the new connection. In both options large changes to the existing Hoogeveense canal will be needed. The water depth of this canal is only 90 cm and it goes under three bridges and through three culverts (among others under the busy railway line between Leiden and Utrecht and a busy provincial road). In addition, a lock would have to be built on the bank of the Old Rhine and space there is very limited.

What this all means is that it will be very difficult and expensive to restore the ancient shipping route from the Bent lake up to the Old Rhine. Restoring the shipping route between the Bent lake and the Rotte faces fewer problems, but they are large too. The most important problems are the railway bridge and the bridge of the A12 motor way near Moerkapelle. If the shipping route cannot be restored completely, the Bent lake may still have value for boating with small sailing and rowing boats and possibly “sloops” (*sloepen*: low open motor boats).

## Spatial design

For the new Hoogeveense canal a spatial design of the south-eastern part of the Gelderwoudse Polder and the Benthuizer Noordpolder has been made (figure 18). These polders are located in the reclaimed Noordplas peat lake directly north of Zoetermeer and Benthuizen. Originally the land plots were small, but many ditches have been filled in and replaced by drainage pipes as a result of mechanisation in Dutch agriculture.

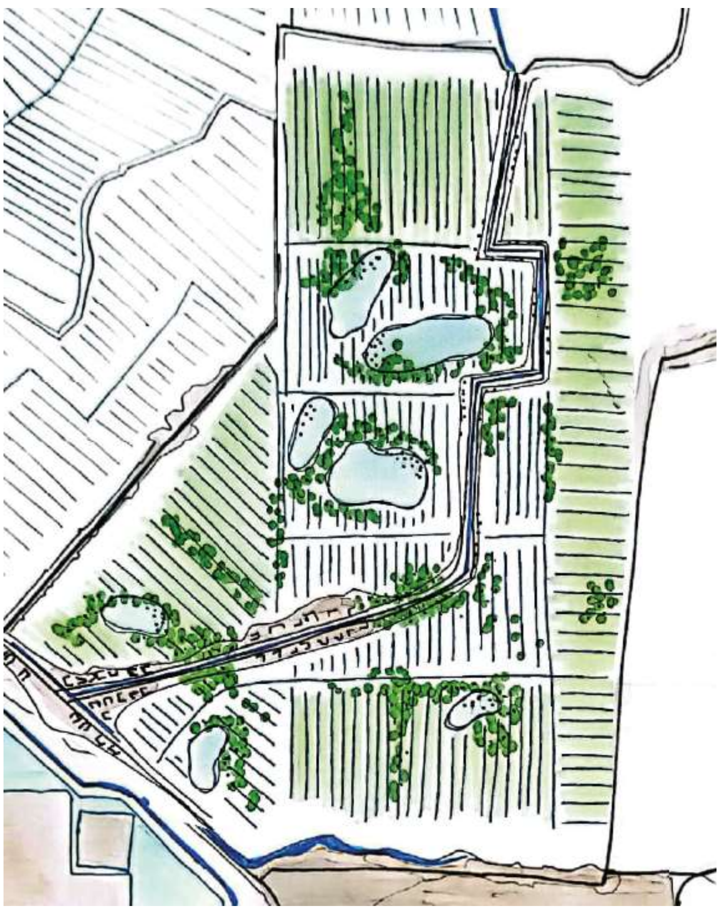

**Figure 18**: Spatial design of the south-eastern part of the Gelderwoudse Polder (the triangular part to the left) and the Benthuizer Noordpolder (Kuit, p. 113)

In figure 18 the new Hoogeveense canal is clearly visible. Starting at the Benthuizer canal, this canal follows the old bed of a creek in northeasterly direction and then changes direction in northerly direction to the existing Hoogeveense canal. The old creek bed provides a solid foundation for new buildings. To limit height differences for boating, the new Hoogeveense canal will be elevated above the polder level. In addition, the higher elevation is a good starting point for telling the history of the landscape with its, literal and figurative, ups and downs. To obtain the necessary soil, small lakes will be dug that provide additional water storage and can obtain a high nature value.

Figure 18 also shows that small land plots are reintroduced. Drainage pipes will be dug up and old ditches will be restored. This requires that agriculture becomes less intensive or is replaced by nature. On the shores of the new small lakes swamps can be constructed and peat might start growing again, albeit at a small scale.

The new buildings along the southern part of the new canal extend the built-up area of Zoetermeer. Instead of terraced houses or expensive villa’s, apartment buildings with four or maximum five floors are proposed. More people will then be able to live at this beautiful location and enjoy the landscape. The apartment buildings will be clearly visible from the polder and from the village of Benthuizen, but a larger part of the polder can remain open than if the same number of housing units would be constructed in the form of terraced houses or villas.

The proposed apartment buildings will become square with one open side to either the new canal or the polder. This result in more lively look than long buildings along the canal, and all apartments can get a good view (figures 19 and 20).

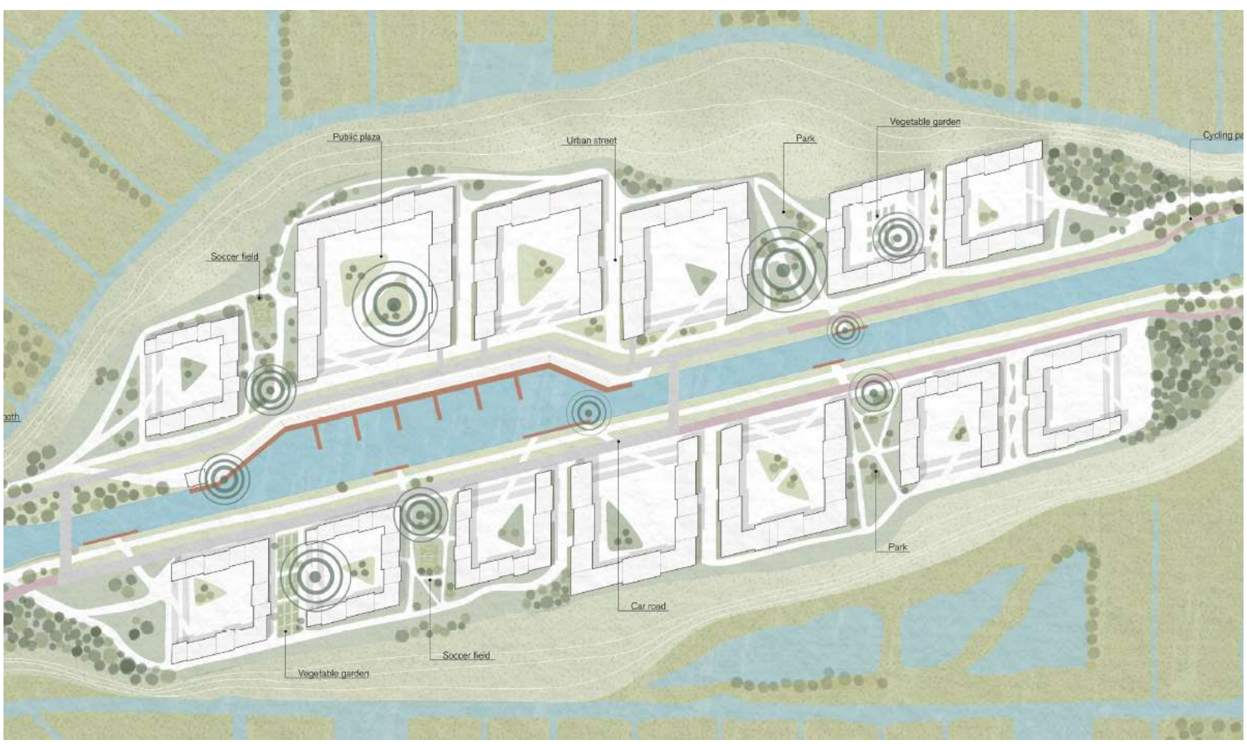


**Figure 19**: Proposed new apartment buildings along the new Hoogeveense canal and the banks with bicycle and walking paths and quays (Kuit, p. 150-151)

**Figure 20**: Proposed buildings (Kuit, p. 165-165)

No detailed designs of the proposed new apartment buildings have been made yet, but they should be futuristic and "green", $CO_2$ neutral, comfortable to live in at higher expected temperatures, and flood proof. Pluvial flooding should not be a problem at all since they will be built above the level of the polder.

The footpaths and bicycle paths along the new canal can be made useable as tow path. There never was a tow barge canal here, but if Zoetermeer had been bigger than Delft already in the 17th Century, it would almost certainly have been included in the tow barge canal network. On the new canal a replica of an original tow barge could be moored and occasionally towed, as is done in the town of Maassluis. The tow barge would be a kind time machine. Coming from the past and moving into the future, the tow barge could be used to tell the story of the drainage of the area, the development of cities and the construction of tow barge canals, but also the story of land subsidence, peat mining and climate change and of the challenges for water management. The destination is not settled yet, but the tow barge could be a good place for a discussion on the destination.

Figure 1 gives an impression of the whole study area with the proposed Bent lake and restored Hoogeveense canal.

What the famous Dutch author Nicolaas Beets wrote in 1838 on planning in the Netherland is still true today: "The plans in our country still travel by tow barge".[57] It would be great if in this case the tow barge could speed up progress so we arrive at a destination in time. There is already a name for the tow barge, the Climate Barge (*Klimaatschuit*), because where the climate is concerned, we are all in the same boat – or barge.

# Noten

1. Renes, H., 2022, *Landscape, heritage and national identity in modern Europe,* Basingstoke, Palgrave Macmillan, p. 8, and art. 1.1 of the Dutch Heritage act (*Erfgoedwet*). When heritage is concerned, the issue at stake is not primarily the past as such, but the present use of the past by specific groups for specific purposes (e.g. Graham, B., Ashworth, G. & Turnbridge, J., 2000, *A geography of heritage,* London, Arnold). Heritage is not always historically correct. Examples of this include the work by the 19th Century Dutch architect Pierre Cuypers, who restored mediaeval building according to his vision of the middle ages, with many battlements and pointed arches, and in the process often removed original elements.
2. Dommelen, S.V. & Pen, C.-J. 2013, *Cultureel erfgoed op waarde geschat; Economische waardering, verevening en erfgoedbeleid,* Den Haag, Platform31.
3. Zanten, M.V. & Vissinga, A., 2020, Cultuurhistorie bij klimaatopgaven, *H2O-Online***,** 1-9; Rijksdienst voor Cultureel Erfgoed, n.d., *Cultuurhistorie als kennisbron voor de klimaatstresstest*, Amersfoort, www.cultureelerf-goed.nl/publicaties; CAS 2022, *NKWK Klimaatbestendige Stad 2021 - Kansen van cultuurhistorie*; and the MOOC (Massive Open Online Course) Water Works: Activating Heritage for Sustainable Development (https://online-learning.tudelft.nl).
4. See for the role of water and water management in the Netherlands for instance Ven, G.P. van de, 1993, *Man-made lowlands,* Utrecht, Matrijs; and Beukers, E. & Aten, D., 2007, *Hollanders en het water: twintig eeuwen strijd en profijt*, Hilversum: Verloren.
5. See for instance Mostert, E., 2020, "Water and national identity in the Netherlands; the history of an idea", *Water History,* 12**,** 311-329, and Renes, o.c.
6. See for example the recent discussions in the Netherlands on the name "Golden Century" (*Gouden Eeuw*) for the 17th Century (e.g. *Historiek; online geschiedenismagazine*, 13 September 2019). Is it allowed to be proud of the Dutch achievements in that period, such as the many land reclamation projects, or are they inextricably linked with colonialism and slave trade since money earned in these trades were invested?
7. Wellenberg, M. & Zee, A.V.D. (red.), 2021, *Atlas van de trekvaarten in Zuid-Holland,* Bussum: Uitgeverij Thoth; and the website Geschiedenis van Zuid-Holland, theme Trekvaarten (https://geschiedenisvanzuidholland.nl/thema-s/trekvaarten/verhalen).
8. De Vries, J., 1981, *Barges and capitalism: passenger transportation in the Dutch economy, 1632-1839*, Utrecht: HES Publishers.
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34 The water levels mentioned in this section are target water levels set by the water board. In case of heavy rainfall they may be temporarily exceeded.
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36 Delfland voert extra zoetwater aan vanwege droogte, press release 14 July 2022, https://www.hhdelfland.nl/actueel/nieuwsoverzicht/2022/juli/delfland-voert-extra-zoetwater-vanwege/
37. See Mostert, E., 2023. De speelruimte voor het waterschapsbestuur, in Vollaard & Binnema, o.c., p. 227-242.
38. See for example the "Dutch championship tile lifting" (*NK tegelwippen*, www.nk-tegelwippen.nl) and Horn, D. van, 2023. *Paving the way; Exploring the potential of green parking and collaborative information sharing between municipalities and companies,* MSc thesis TU Delft, http://repository.tudelft.nl.
39. The provincial waterways in the area are also bosom waters, which are managed by the water boards. Consequently, they have two managing bodies.
40. Zuid-Hollandse Omgevingsverordening – toelichting, p. 53.
41. Art. 2.1 Waterwet, Annex to art. 1.1 Omgevingswet, part A; and Mostert 2023, o.c.
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43. See for example Alphen, J. van, Haasnoot, M. & Diermanse, F., 2022, "Uncertain accelerated sea-level rise, potential consequences, and adaptive strategies in the Netherlands", *Water* 14(10): 1527; Haasnoot, M., Diermanse, F., Kwadijk, J., Winter, R.D. & Winter, G., 2019, *Strategieën voor adaptatie aan hoge en versnelde*

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49. Since November 2022, this is official government policy: Minister of Infrastructure and Water Management, Kamerbrief Water en Bodem sturend, 25 November 2022, Kamerstukken II, 27.625 nr. 592.
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51. The 2013 KNMI climate scenarios have been used because the new KNMI scenarios from 2023 became available too late for the research.
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53. In this research, the costs have not been quantified. See for a quantification of some of the costs of a new shipping route between the Rotte and the Old Rhine the report *Rijn-Rotte-Vliet; Van vaarverbinding naar groenblauwe gebiedsontwikkeling* uit 2017. This report does not discuss the costs of alternative measures to address pluvial flooding, the costs of drought and the costs of measures against drought.

54 Currently, $CO_2$ emissions as a result of oxidization of peat in the so-called Green Heart is 1.4 mln ton per year. This is more than the $CO_2$ emissions of all houses in the Green Heart municipalities, which have been estimated at 1.3 mln ton (PBL, 2015, *Het Groene Hart in beeld; Een uniek veengebied midden in de Randstad*, The Hague: Planbureau voor de Leefomgeving).

55 See Jansen, A.J.M., Duinen, G.A. van, Tomassen, H.B.M., & Smits, N.A.C., 2014, "Herstellende hoogvenen", in: *Herstelstrategieën stikstofgevoelige habitats*, Deel II, p. 671-700, www.natura2000.nl.

56. Van Tielhof & Van Dam, o.c., p. 56-57 and 75 and the literature mentioned in endnote 19.
57. Hildebrand, 1839, Varen en rijden, *Camera Obscura.* Haarlem: Erven F. Bohn, p. 139-156. First published in *Studenten almanak voor het jaar 1838*, Leiden: L. Herdingh en zoon.